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[625 .258 (.492) & 656 .259 (.492)]

Results obtained with the track brake : « Thyssenhütte System », (1)

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Figs. 1 to 4, pp. 6 to 10.

In continuation of our report on question III : « Shunting yards » to the London Congress (2), we think it will be of interest to report the results obtained from the new track brake « Thyssenhütte System » in the marshalling yard at Susteren in Holland. As figure 1 shows, the yard at Susteren, which is in the South of Holland in the province of Limbourg, is specially used for sorting of wagons from the coal field which are to be sent to the North of Holland. Consequently, nearly all the wagons dealt with at the shunting neck are of 10, 15 and 20 t. capacity loaded with coal or coke. The wagons are brought in by local trains from the different mines. The reception sidings have been laid down before the shunting neck is reached; the wagons sorted on the marshalling sidings are sent forward to the different destinations by fast, semi-fast or stopping trains.

Wagons from the collieries for Belgium and France are sent direct to Lanaeken or Visé; those for Germany to Herzogenrath or Aix-la-Chapelle.

At the present time, about 65 % of the total output of the mines is sent to the North, and with the exception of two trains daily, which are sent direct from Nuth to the ports of Rotterdam and Amsterdam, go into the yard at Susteren.

800 to 900 wagons are dealt with daily at Susteren, so that the shunting can be done in a period of sixteen hours each day.

Before the « Thyssenhütte » track brake was installed and the shunting neck altered, the profile of the hump was :

1 in 40 for a length of 48 m. (52 yards);
1 in 100 for a length of 40 m. (44 yards);
1 in 400 for a length of 200 m. (220 yards), and then level.

(1) Translated from the French.

(2) *Bulletin of the International Railway Congress Association*, February 1925 number, p. 237.

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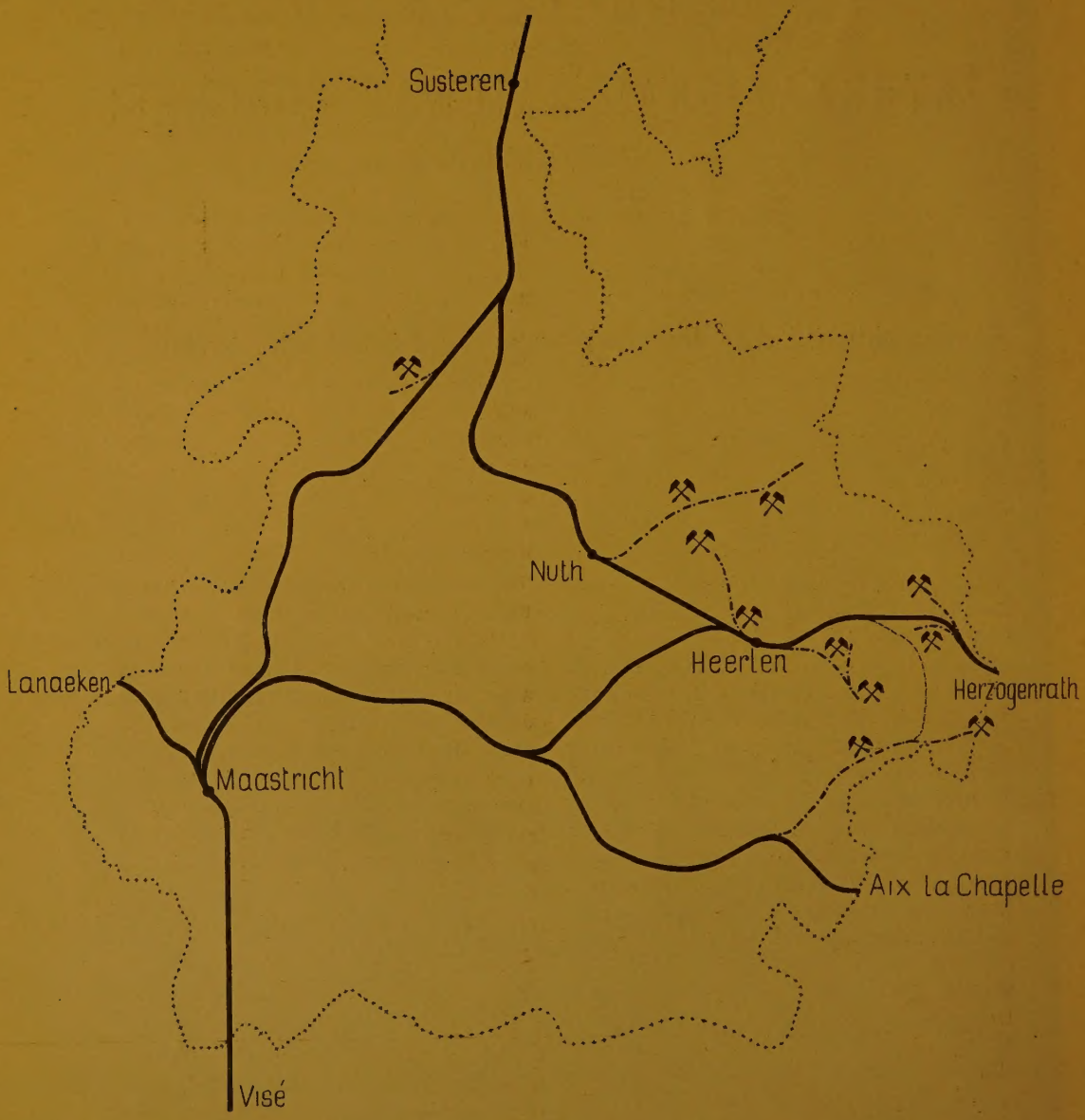

Susteren
Nuth
Heerlen
Herzogenrath
Lanaeken
Maastricht
Aix la Chapelle
Visé

Fig. 1.

Wagons running down from the hump were stopped by shoe brakes in the sorting roads. As we shall see later, the shoe brakes frequently did not act properly, either because the friction on the rail was insufficient, or because they were thrown off the rail. As a result, free running wagons under favourable weather conditions ran down too quickly and collided with those already standing in the sorting sidings, damaging the wagons and their contents. Frequently the doors and sides of the open wagons opened as a result of the violent shocks and part of the contents was thrown out.

During the last three months before the track brake was introduced, 19 007, 17 780 and 19 343 wagons were shunted with the following results :

First month : 39 shoe brakes thrown off the rails; 8 loads partly thrown out by rough shunts; 6 axlebox bottoms broken; 1 bridle broken; 2 buffers bent; 1 buffer beam broken. Repairs to the shoe brakes cost 105 florins.

Second month : 67 shoe brakes thrown off the rails; 9 loads to reload. The following damage was done : 3 axlebox bottoms broken; 3 guards broken; 1 bridle broken; 12 buffers bent. The repairs to the shoe brakes cost 122.5 florins.

Third month : 98 shoe brakes thrown off the rails; 10 loads to reload. The following damage was done : 6 axlebox bottoms broken; 7 guards broken; 3 buffers bent; 1 buffer broken; 2 wagon ends damaged; 1 bearing spring top plate broken. Repairs to the shoe brakes cost 120 florins.

Taking into account seen and unseen damage to stock, loss of revenue through slower turn round of the damaged stock, it can be taken that the cost of repairs, etc., certainly comes to 4 cents per wagon shunted, that is to say, to 800 florins for a traffic of 20 000 wagons a month.

The installation of the track brake coincided not only with an alteration to the end of the fan of sorting sidings, see figure 3, but also with a rearrangement of the hump profile which was altered to a down gradient of 1 in 20 for a length of 44 m. (48 yards) (fig. 2); 1 in 80 for a length of 26 m. (28.5 yards), on which the track brake was fitted, and 1 in 400 for a length of 225 m. (246 yards) at the beginning of the sorting sidings which are on the level. Figure 4 shows the control gear in the cabin. Within a few days of the track brake being put into use, the damage to stock was noticeably reduced, and it was most interesting to observe how quickly the staff learnt to use the brake. The first month after the track brake was put down, only 41 % of the wagons shunted had to be stopped in the sorting sidings by means of shoe brakes. The results obtained were most satisfactory: only four cases occurred in which the shoe brakes did not act, and from only five wagons was part of the contents thrown out. Repairs to shoe brakes cost 17.50 florins only.

The result has been to show, not only an appreciable reduction in the number of cases of damage and in the extent of the damage done, but also to give greater safety in carrying out the shunting. Furthermore, the installation of the plant has allowed an increase in traffic to be met without having to extend the period dur-

Fig. 2.

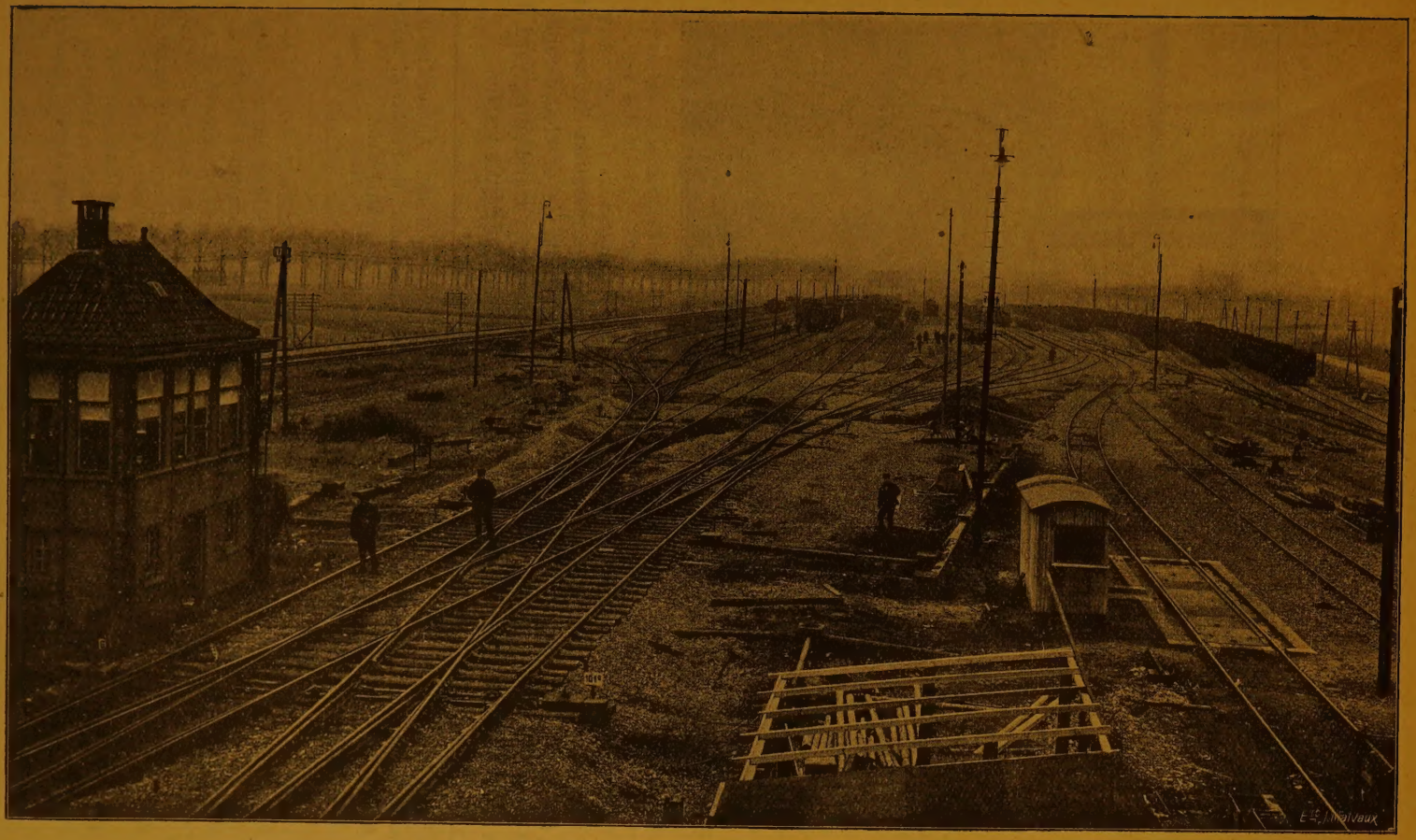


Fig. 3.

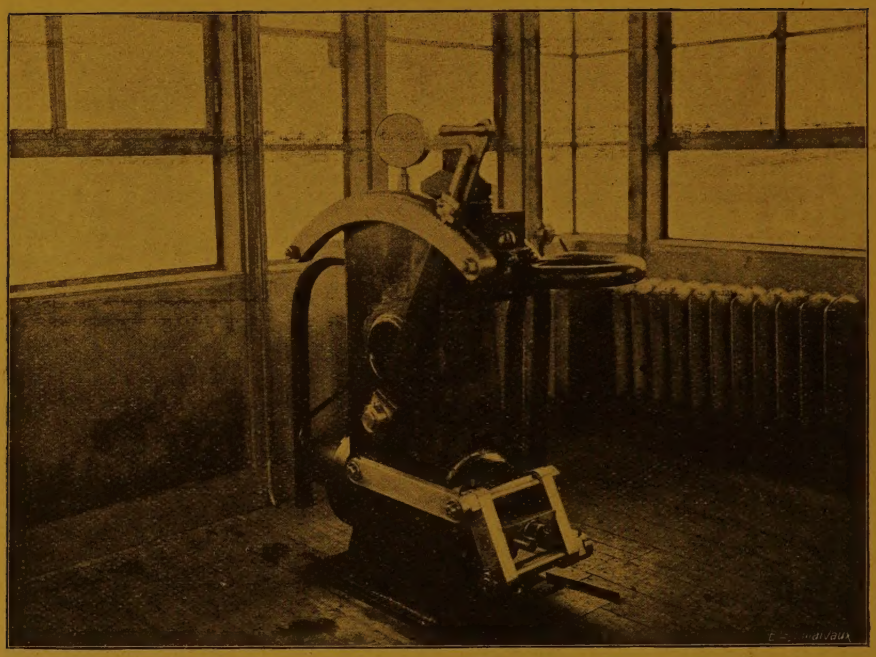


Fig. 4. — Control gear.

ing which shunting has to be done during the twenty-four hours (1).

We can therefore come to the conclusion that from the point of view of safety and economy in operation, the use of this new track brake is of considerable advantage even in a marshalling yard dealing with relatively little traffic.

(1) The use of the track brake also makes it possible to effect some saving of staff. Although the number of tracks was increased by three when the fan of sorting sidings was altered, the number of brakesmen was reduced by one; one of these employees was in fact put to work in the control cabin.

[625 .258 (.73) & 656 .259 (.73)]

The development of car retarders.

Figs. 1 to 7, pp. 12 to 15.

(*Railway Signaling.*)

A system of car retarders, designed to eliminate car riders, has been developed during the last 18 months on the north hump of the Indiana Harbor Belt classification yard at Gibson, Ind. These braking units or retarders, as developed under the direction of George Hannauer, vice-president, are operated by air pressure controlled electrically from five towers by operators who also control the switches.

The retarder units consist of a series of shoes which, backed by strong springs, grip the edges of the car wheel rims as a car passes by. The pressure behind these shoes is controlled through a set of levers connected to the piston rod of an air cylinder. This set of levers, as shown in one of the photographs, consists of several sets of two levers each, one of which pushes the outside brake toward the rail, the other lever, connection for which passes under the rail, pulls the inside brake toward the rail. These levers are so connected to one bar that a movement in one direction gives the desired operation of all levers.

The arrangement of a car retarder unit including supporting angles, brake shoes, brake cylinder and operating levers is illustrated herewith. The brake shoes are subject to wear and hence are renewable, provision being made in the design to reverse the shoes as their condition of wear may require, and to take up slack.

The air pressure in the cylinder is controlled through electro-pneumanic valves operated electrically from levers in the towers. Three pressures, 40 lb., 80 lb. and 120 lb., can be given, and a fourth position throws air in the other end of the cylinder to open the retarders wide.

Also forming a part of this new system are automatic « skate » machines for placing « skates » (Scotch blocks) under car wheels to stop the car quickly in case it is getting out of control. This machine is also operated by air pressure controlled electrically. The « skate » lies in an arm connected to the cylinder piston. When the machine is operated the arm sets the « skate » on the rail and the arm returns to normal position. Another « skate » must then be placed on the machine by one of the yardmen.

General method of operation.

There are a total of 51 car retarder units in the yard, varying from 24 feet to 40 feet in length and located as shown in figure 2.

The car retarders may be applied to both rails of the track or to a single rail. It was at first thought that the application of pressure to the sides of the wheel rims on only one side of the car would have an undesirable swiveling action on the trucks but experience showed that this effect is not produced and as a consequence the application of the car retarder units, particularly opposite switch points, is greatly simplified.

The car retarders and switches are operated from the five control towers,

Fig. 1. — General view of Gibson yard showing car retarders, switches and operating towers.

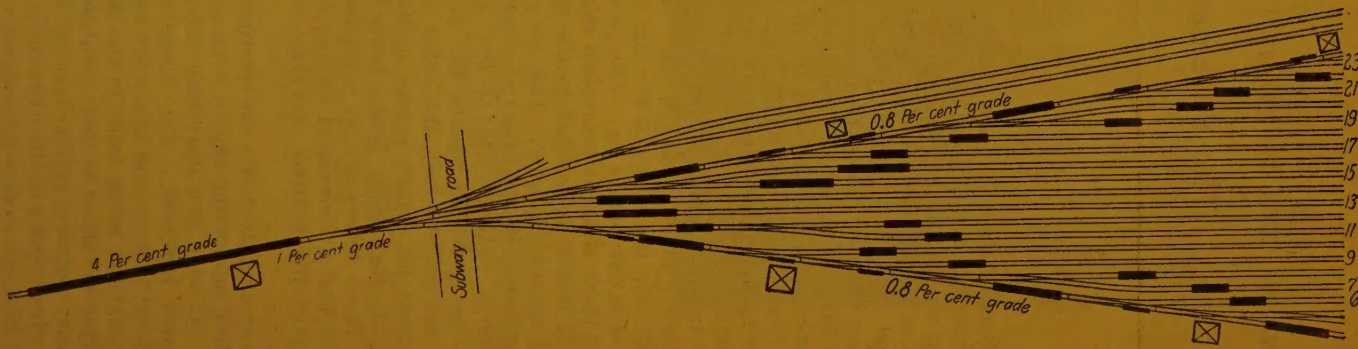


Fig. 2. — Location of car retarder units on the North hump of Gibson yard; positions of the five control towers are indicated by crossed squares.

indicated by crossed squares, in the yard plan, through the proper manipulation of electric lever switches. When a car is released at the hump it enters the first car retarder unit and the sides of the wheel rims are gripped with a pressure determined by the tower operator in accordance with his advance knowledge of the weight of the car and probable braking effort necessary to retard it the required amount.

The car then passes on to the car retarder units controlled from the second and in the case of the most distant tracks, from the third tower. It passes the last tower with just enough speed, as determined by the judgment of the tower operator, to carry it to the last car on the particular track to which it is switched. The towers are in constant inter-communication by means of loud speakers, and the transmitters are so placed that the operators can talk while still watching the track and operating the levers. In case of necessity skates can be placed on the rails by the operation of suitable valves in the control towers. The provision of the skate-throwing machines is a decided safety feature since it obviates the necessity of a switchman ever placing a skate in front of a moving car. A field man at the far end of the yard sets the brakes and prevents the cars bumping out. This man is also available when it is necessary to push down the cars on any track.

The effectiveness of the car retarders is indicated by the fact that a car can be readily stopped in the braking unit on the 4 % grade at the hump whereas it takes 10 or more car lengths to stop a car with the hand brake. Some roads are having difficulty in hold 70-ton capacity coal cars with only a single car rider to apply the brakes but cars can be stopped by the car retarder units at any desired point. If the operators allow a car to attain a considerable speed, much more braking power in the aggregate is required at the last car retarder than if the speed of the car is kept at a desirably low point by light applications of pressure as it passes each of the retarders. Complete control of even the heaviest cars enables them to be spaced uniformly and put over the hump at the rate of three a minute. A continuous handling of cars at this rate, however, would require a large volume of business and the services of three engines in the receiving yard to get the cars up to and over the hump as fast as they can be disposed of.

The duties of the tower operators consist of controlling the retarders, operating the power switches and operating the skate-throwing machines. These men work on three shifts. A vital feature of their work is the study of accurate switching lists showing the amount of load. In other words, the tower operators must know in advance something about the weight of each car to assist them in making the required brake retarding effort.

The switching list as now prepared shows the number of cars in incoming trains in numerical order with the car number, railroad and condition as regards load or empty. The letters LL indicate a light load, XL heavy load, L ordinary load, and E empty. The destination of the cars is also shown on the switching list, bad order cars being indicated so that they can be switched to the repair track.

Switch operated electro-pneumatically.

As the system developed it was seen that the retarder operators had plenty of time to also operate the switches if the proper control were installed. Therefore, within the last few months all of the switches were connected to be operated electro-pneumatically. The levers in the tower control electro-pneumatic valves located near the switches which control the passage of air to one side or the other of a piston. As the switch is connected to the piston rod, the switch

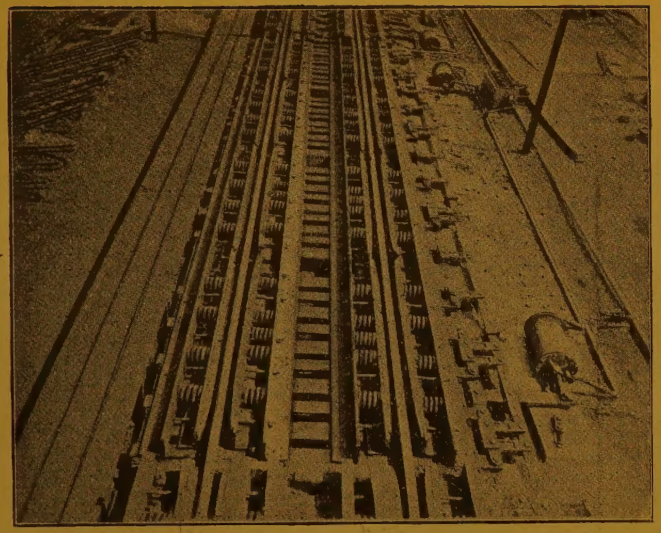


Fig. 3. — The retarder set on the main hump head is of the latest design.

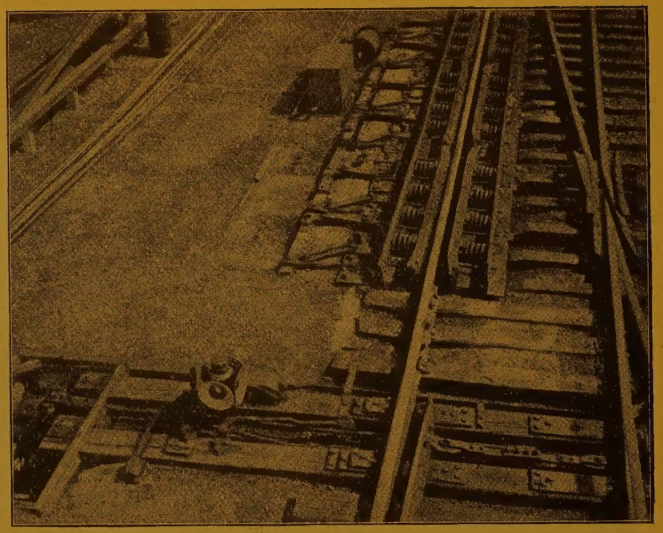
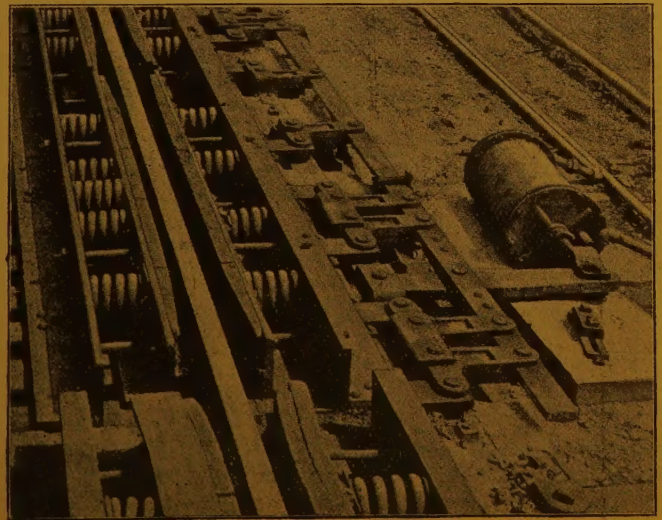
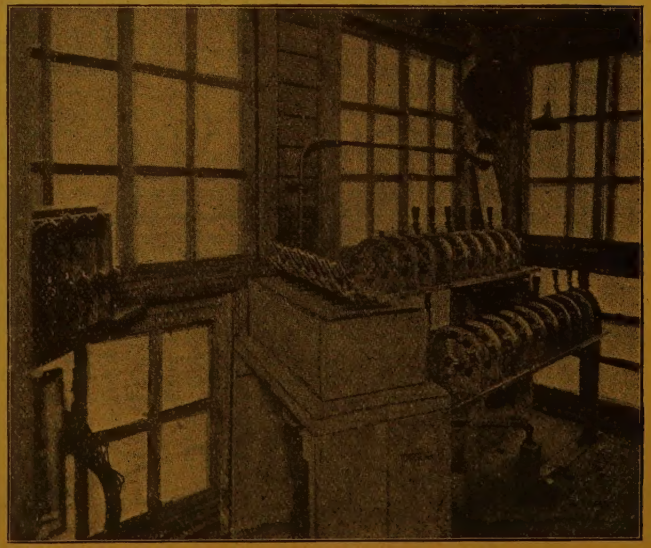


Fig. 4. — Car retarder as applied to single rail ; also part of electro-pneumatic switch machine with hand throw emergency feature.





is thus operated and held in position by air pressure, there being no locking feature to the mechanism. No track circuit control or locking of any kind is used in connection with these switches, this sort of operation being practicable due to the fact that each operator is located within a short distance of the switch he controls and can judge the position of cars quite closely. The switch stands and rods are left in place so that the switches can be thrown from the ground if desirable.

Fig. 7. — Skate-placer machine with cover removed, showing skate in place on rail and holder returned to normal position.

Advantages of the system.

While this development is subject to further alteration and refinement, its success is amply demonstrated by the results already accomplished. These results may be summarized as follows : 1) All car riders on the north hump are dispensed with, thus saving the labor of 66 men, or approximately $385 a day with the present volume of business; 2) cars are spaced more uniformly and closely with a consequent potential increase in yard capacity; 3) complete control of cars on the grades prevents rough handling and damage claims; 4) the use of an outside braking medium obviates the necessity of preliminary train brake tests; 5) the elimination of car riders promotes safety, particularly in winter when the cars, ladders, hand holds and hand brake wheels are often covered with snow and ice; 6) the provision of a mechanical device for placing skid shoes or skates on the rails at the will of the tower operators removes the danger from this operation.

Retarder system for peak traffic.

The important problem in the operation of a classification yard is the development of full capacity during periods of maximum demand. The peak traffic in the Gibson yard ordinarily occurs in the autumn and winter, after the close of navigation on the lakes, and in the past when the yard was operated with car

riders, its capacity in the winter was often seriously limited by a shortage of men, the necessity for training new men under heavy traffic conditions, and the general inefficiency of men during extremely cold weather.

As the number of riders could not be adjusted within an eight-hour period, any unusual increase in the number of cars to be classified during the day resulted in congestion because the number of cars that could be handled would be limited by the number of riders on the job. The car retarder system has, therefore, proved to be an important factor in smoothing out these peaks, due to the fact that its full capacity is available at all times. The only important remaining variable factor affecting the use of the yard to full capacity is the number of pusher engines in service and additional engines can be called within short notice.

During the periods of peak service in previous years, it has been necessary to use the Burnham yard as an overflow for the switching of Baltimore & Ohio trains and some of the New York Central trains that could not be handled at the Gibson yard. During the season just past it was found that all of the traffic offered could be handled at the Gibson yard, with the result that a portion of the Burnham yard was leased for other purposes. The l.c.l. freight formerly switched at Gibson Transfer, and also considerable switching that was previously handled at the Michigan Avenue yard, is now being handled at the Gibson yard at a lower operating cost. The car retarder system has thus definitely increased the capacity of the Gibson yard and has decreased the cost of switching traffic formerly handled at these other yards.

Cars handled per man increases 84 %.

The function of the car retarders in saving labor will perhaps be better appreciated from an examination of figures showing the cars handled and men employed in October 1924 as compared with October 1923. There are two humps in the Gibson yard and on 23 October 1923, a total of 2 665 cars were handled over both humps with 105 car riders and switch tenders, or an average of practically 25 cars per man. On 23 October 1924, after installation of the car retarders, 1 667 cars were handled over the north hump with a total of 39 men including 24 switch tenders and 15 car retarder operators. In other words practically 43 cars were handled per man; an increase of 84 %. As expected, a still further reduction in force of 12 men was made following the installation of power switch-throwing machines in place of the hand-operated switches now used. The best performance on the north hump to date, using the car retarders instead of individual car riders is 1 042 cars in eight hours. In one case 220 cars in three long trains were handled over the hump in 80 minutes, but this represents a performance above the average.

Operation under winter conditions successful.

The installation of car retarders for the entire westbound hump yard at Gibson was completed 1 December 1924, at which time all car riders were eliminated.

A portion of the winter of 1924-1925 was extremely cold so the car retarder system was given a test that is believed to be representative of its efficiency during winter weather. The temperature was as low as 20° below zero, with several snowfalls, one of which exceeded six inches. Two severe sleet storms occurred which covered the ground, tracks and equipment with a thick coat of ice. The sleet was so heavy that it was necessary to use mauls to break the ice on the drawbars in order to uncouple the cars at the crest of a hump. These sleet storms did not interfere with the successful opera-

tion of the car retarding system, because the operating mechanism is provided with a surplus of power, and the machines are operated with sufficient frequency to prevent any great amount of ice forming on the working parts. A few of the machines were equipped with steam pipes to melt snow. It was found, however, that the snow could be blown away so easily by compressed air that the installation of the steam equipment was not justified in this climate.

The capacity of the yard developed under the adverse weather conditions exceeded any previous record with hump riders under similar conditions. Obviously the operating speed of a humped car was affected by the cold and the winds to the same degree as in previous years, but aside from this factor, the weather did not decrease the yard capacity.

February was the first month in which the yard was in full operation without hump riders or ground switch tenders, and the results of the operations in February 1925, as compared with February 1924, are shown in the table. As February 1925 was a typical winter month, these figures will give a fair idea of what may be expected under normal winter conditions.

Item.	Quantities.		Costs.	
	February 1924 (29 days).	February 1925 (28 days).	February 1924.	February 1925.
1. Cars humped	42 534	45 283	...	...
2. Average per day	1 467	1 617	...	...
3. Mean temperature	30°	30°	...	...
4. Engine hours	1 840	1 338	$ 19 320.00	$ 14 149.00
5. Conductor hours	696	648	577.68	537 84
6. Switchmen hours (includes car riders)	14 192	2 787	10 927.84	2 145.99
7. Switchtender hours	3 480	...	2 053 20	...
8. Hand-brake testers	58	...	400.00	..
9. Retarder operator hours	...	3 360	...	3 124.80
10. Messenger service hours	...	270	...	122.50
11. Maintenance	...	...	...	1 758.05
12. Power	...	...	..	1 124.73
13. Personal injuries	...	...	2 263.00	55.25
		Grand total	$ 35 541.72	$ 22 918.16
		Average cost per car humped	83.5 c.	50.6 c.
		Total saving, February, 1925, over 1924	...	$ 12 623.56
Savings not included in the above :				
14. Saving in cleaning yard.				
15. Reduced car damage.				
16. Reduced freight damage.				
17. Increased humping capacity.				

Explanation of savings.

A study of the cost of enginemen's and firemen's wages, coal, water, cost of engine repairs and roundhouse service, and interest on investment, led to the conclusion that $10.50 per hour was the average cost per engine hour for pusher service. An average of 150 more cars were handled per day in February 1925, than in a day of the corresponding month of the previous year. However, as shown in the table, there was a reduction of 502 engine hours in February 1925, as compared with February 1924. This difference represents a saving of $5 171, and is ascribed to the flexibility afforded by the retarder system.

One factor contributing to this result is that the yard was able to switch the cars without any delay incurred in waiting for riders to return to the hump. Another advantage is that the car retarders space the car cuts more accurately, greatly reducing the chances of a car being put in the wrong track as was frequently the case under manual operation where an insufficient space between two cuts did not allow the switch to be thrown. Trimming is expedited with the zoning system under which the car retarder operators control the switches in their respective zones. At certain intervals different sections of the yard can be trimmed without seriously slowing up the flow of cars down the leads. All of these factors have effected a more uninterrupted operation of the yard and a saving in engine hours.

Previously, with the use of car riders it was necessary to inspect the hand brakes in a receiving yard, and as hand brakes are not required with the car retarder system this inspection is no longer necessary. The item, messenger service hours, covers the charge for a messenger now required to deliver train lists to the various retarder operators. However, this expense is temporary, inasmuch as a pneumatic tube system is being installed to perform this delivery service.

Included in item 11, maintenance payroll and maintenance materials, is the cost of handling snow and the cost of some service tests with the retarder shoes. Upon the completion of this experimental work it is expected that the average maintenance will eventually amount to about half of the cost shown. Item 12, power, includes the labor charge for the operation and maintenance of air compressors, the cost of power for operating a system, and the cost of blowing snow out of the switches. By assigning other duties to the compressor attendants it is expected that this cost will be reduced by $220 per month.

Other substantial savings not considered.

The car retarder system is responsible for other substantial savings which cannot be figured accurately. The elimination of severe impact has reduced the spilling of freight such as coal from the cars, thereby reducing the amount of section labor and work train service necessary to clean the yard and pick up freight. The reduction of the impact between cars has substantially reduced the damage to cars and lading, but the damage records are not kept in a way that permits of a segregation of the damages occurring in hump yards. It is estimated that losses on this score have been reduced two-thirds. When the installation of the new type of « skate » machine is completed damages from impact will be further reduced.

Damages resulting from personal injury to the car riders and switch tenders was formerly a serious factor in yard operation. During winter weather when the cars and the ground were covered with snow or sleet serious personal injuries were a common occurrence, and the table shows that damages on this account averaged $2 263 per month for the year ending 31 March 1924. Accidents of this nature were practically eliminated by the installation of the car retarders and automatic skate machines.

In addition to the increased capacity and safer operation resulting from the use of the car retarders a better class of men can be employed. The night hump car rider's job is the most hazardous and least desirable position about the yards and consequently the one on which new men break in. Obviously the difficulty of getting men of desirable qualifications to enter railroad service at freight car yards is directly proportional to the unattractiveness of this work.

The idea of installing some sort of a braking device at freight classification hump yards to obviate the necessity of employing car riders is not new but it is believed that the development at Gibson is the first practical and successful application of the idea. The entire equipment including car retarder units, tower control equipment and skate-throwing machines is covered by patents held by George Hannauer, vice-president, and E. M. Wilcox, master car builder of the Indiana Harbor Belt.

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How present day track design was developed,

By Geo. E. BOYD,
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(*Railway Review.*)

It is impossible to trace with certainty either the date, or the manner in which the earliest forerunners of the present form of railway track were devised. It has been said the application of the principle on which their value depends may be traced to the construction of early Italian streets, especially those of Milan where a smooth surface is provided for the passage of wheels and a rough one on which the horses may tread with security.

It is probable the adoption of artificial roads first took place where considerable quantities of goods had to be conveyed between two points. Where wagons continually passed along the same road and where the cost of upkeep was expensive, it may be a remedy was sought by laying down timbers over the worst part of the road. This might lead to the introduction of wooden rails over the entire distance the commodity had to be transported.

All authorities seem to agree that the first definitely formed railways were in use between the collieries and docks at various points in England, particularly in the neighborhood of Newcastle-upon-Tyne. A record in the books of one of the free companies in Newcastle, dated 1602, states. « That from tyme out of mynd yt hath been accustomed that all cole-waynes did usually carry and bring eight baulls of coles to all the staythes upon the river of Tyne, but of late several hath brought only, or scarce, seven baulls. » A boll is equal to six Winchester bushels. The cost of transporting such heavy material as coal along common roads, which probably were not of the best, in carts containing seven or eight bolls would furnish a powerful incentive to introduce some improvement in the mode of conveyance, both to overcome the difficulties encountered and to lessen the expense.

In a work published at Newcastle in

1649 in an account of the coal trade it is stated, « Master Beaumont brought with him... rare engines to draw water out of the pits; waggons with one horse to carry down coales from the pits to the staythes to the river... ». The ordinary form of cart used on public highways has been denominated wain or wayne in England for centuries. It will be noted the carriages introduced by Master Beaumont were called waggons, and ever since that time carriages used on railroads in England have been termed waggons. We might infer from this that the « waggon » was used upon a railway and that Mr. Beaumont was the first to introduce them into the North. While this is mainly speculation, doubtless the date of introduction of the earliest form of track was between 1602 and 1649. At any rate this type of track was a common form of construction in 1676.

Roger North, in describing a visit paid by his brother, Lord Guildford, to Newcastle, remarks that among the curiosities of the region were the « wayleaves ». Me says, When men have pieces of ground between the colliery and the river, they sell leave to lead coals over the ground, and so dear that the owner of a rood of ground will expect £20 per annum for this leave. The manner of the carriage is by laying rails of timber from the colliery down to the river, exactly straight and parallel, and bulky carts are made with four rowlets fitting these rails, whereby the carriage is so easy that one horse will draw four or five chaldrons of coals and is of immense benefit to the coal merchants. » A Newcastle chaldron contained 72 Winchester bushels.

First iron rails

An iron tramroad was in use at Colebrook Dale about the year 1760. The price of iron had fallen and, in order to keep the furnaces at work, it was determined to cast plates to be laid on the upper edge of the wooden tram railys. It was thought this would diminish friction and prevent abrasion, while the iron could be sold in case there occurred a sudden rise in price. These scantlings of iron were four inches wide, one and one quarter inches thick and five feet long. They were cast with holes for the purpose of fastening them to the wooden rails. So successful was the experiment, however, that the plates remained undisturbed, and iron rails were gradually adopted in that district. Fifty years later there was about 180 miles of this type of railway in South Wales, 30 of which belonged to the Merthyr Tydvil Co. Upon nine miles of this track, at Penydawan, built in 1800, the first railway locomotive ran in February, 1804.

Early track described.

The earliest detailed description of railway track is found in Jaa's *Voyages Métallurgiques,* volume 1, page 199, published 1765. The description follows: « ...there are afterwards arranged, along the whole breadth of this excavation, pieces of oak wood, of the thickness of four, five, six and even eight inches square : these are placed across and at the distance of two or three feet from each other; these pieces need only be squared at their extremities; and upon these are fixed other pieces of wood, well squared and sawed, of about six or seven inches breadth by five in depth, with pegs of wood; these pieces are placed on each side of the road along its whole length; they are commonly placed at four feet distance from each other, which forms the interior breadth of the road. »

The unprotected timber occasioned much waste because the rail,when partly worn, was unable to support the weight of the vehicles and it was necessary to renew it frequently. An early effort to overcome this trouble resulted in the addition of another rail on top of the one resting directly on the sleeper to be used as a wearing surface. This type of con-

struction was called the « double way ». The wearing surface could be worn out almost completely before the strength of the track was affected and before it was necessary to make renewals.

The sleepers, or ties, for this type of construction generally were what are now known as pole ties. The top of the tie was placed flush with the surface of the ground, but here another difficulty arose. The horses wore the dirt away from between the ties, making it a matter of considerable difficulty for them to walk in the center of the track. Furthermore, the destruction of the ties from abrasion by the horses' feet was quite rapid. To overcome this trouble the height of the rail was increased somewhat and the space between the rails filled with broken stone or ashes. This failed to overcome entirely the difficulty, and, probably, the trouble just mentioned had considerable to do with the change in type of track construction which then took place. With the introduction of iron rails, stone blocks from 18 inches to two feet square were substituted, generally, for the wooden ties, and for many years, both in England and in this country, constituted the accepted standard for track construction. It was only when the weight of the motive power and rolling stock became too great for the stone blocks to remain in surface that the wooden tie was again brought into use.

Stone foundation used

The stone foundation was introduced by Benjamin Outram, an engineer on the public railway at Little Eton, Derbyshire, in 1800. A stone block, instead of the usual timber sleeper, was introduced for supporting and joining the ends of the rails. Mr. Outram, however, was not the first to make use of this method of track construction as there was a line laid from Lawson main colliery to the river at Newcastle-upon-Tyne in 1797 where this form of support was used.

The first form of iron wearing surface was simply plates. Shortly after the Colebrook Dale experiment, cast iron rails with an upright flange were invented and first used near Sheffield. The next type of rail was known as the edge rail. This was introduced at the slate quarries in Carmarthenshire, Wales. The metals, as they were called, were between four and five feet long. They were somewhat oval shaped in section. The wheels which ran upon them had grooved tires similar to pulley wheels. Subsequently it was found that the grooves became so deepened by wear as to fit the rail tightly and cause unnecessary friction. The bearing surface of the rail and the corresponding part of the wheel were then made flat and it was found that two horses could draw a train weighing 24 tons with comparative ease, and could handle a traffic which, on a common road, would have required the use of 400 horses.

The capacity of the carts used on these railroads were increased to a point where a good many broken rails resulted. Various improvements were suggested until finally fishbelly rails were designed. These were made three or four feet long with their greatest depth at the middle. They were supported at the ends and secured to one another by a chair or iron box so fixed to the wooden or stone support that a continuous track resulted.

Flanged wheels introduced

The greatest improvement made in track construction came when William Jessop, in 1789, constructed a railroad at Loughborough, Leicestershire. Jessop was an engineer. He decided to abandon the flat wheels and flanged rails and to reverse the arrangement by using flat top rails and wheels with flanges cast on the tire. These rails also were known as edge rails because the wheels ran upon the upper edge. They were cast iron, three feet long, and had a

single head one and three quarters inches wide. They were of the fishbelly pattern and were fastened to cross sleepers by means of iron pins or bolts which passed through a projecting base at the ends of the rails. The cast iron projections broke off and the rails were rendered useless because there was then no way to fasten them down. This lead to the introduction of the chair, which has already been mentioned and which was an important improvement. The plan of holding a chair to the tie and fastening the rail in the chair by means of a key driven between it and the chair is in use in England to this day.

Gauge established

The usual width of the old wooden and cast iron tramroad practically determined the gauge of our present railways. The usual width or gauge was five feet over all, including the width of the two rails. Jessop's edge rails as the Killingworth tramroad had rails one and three quarters inches wide. This gave a distance of 4 ft. 8 1/2 in. between the inner edges of the rails. Stephenson adopted this gauge for the Stockton & Darlington and the Liverpool & Manchester railways. He was consulted as to the gauge for the Leicester & Swanington and the Canterbury & White Stable railways. Without specifying the gauge to be used he replied, « Make them of the same width. They may be a long way apart now, yet, depend upon it, they will be joined together some day. » Fishbelly rails 15 feet long were adopted for all of these lines.

The design of flat top rails and flanged wheels by Jessop in 1789 was an organic change which made possible the present form of railway transportation. High speeds and heavy motive power or rolling stock would not be possible with the flangeless wheel and flanged rails of the early track design. By putting the guide on the wheel instead of on the rail Jessop made our modern railway development possible.

First American railway

The first American railroad was built by Silas Whitney, on Beacon Hill in Boston, in 1807. Thomas Lieper engaged a millwright, named Somerville, from Scotland, who had seen tramways in his native land, to lay a track at a grade of one and one-half inches to the yard. This track was 60 yards long and was laid down at Bulls Head Tavern in Philadelphia in September, 1809. In May, 1809, he made estimates of the cost of such a line from his quarries. In February, 1810, he estimated that a railroad three quarters of a mile long, leading from his quarries to the landing place at Crumb Creek, had cost, including the survey, $1 592.47. This railroad was completed under the direction of John Thompson, father of J. Edgar Thompson who subsequently became president of the Pennsylvania Railroad. The third railroad, or tramroad, probably was the one constructed on Falling Creek, Chesterfield county, Virginia, about ten miles from Richmond, in the latter part of 1810 to supply transportation facilities for a powder mill. This road was about a mile long and ran between the powder mill and a magazine. The gradient was about eight per cent. One rail was grooved and the other tongued. They were cut out of solid timber and the track was floored the entire length of the road. At one point the line passed over a valley about a quarter of a mile wide. Here it was necessary to use a trestle approximately 75 feet high. The wagons were very large, having bodies 18 or 20 feet long. Wooden wheels, two feet in diameter, were made of double plank of hard wood, cross grained to each other. The wheels on one side were tongued and on the other grooved to suit the respective rails. There was a lever or brake to control the speed of the downgrade movement. Empty cars

were hauled back to the mill by means of a cable wound on a vertical drum. The powder mill blew up in 1819 and the road was abandoned.

The fourth tramway was built at Bear Creek Furnace, Armstrong county, Pennsylvania, in 1818. The fifth was laid in Nashua, N. H., in 1825, and the sixth was the Quincy Railroad in Massachusetts, about four miles long, built in 1826 to haul granite to the port of Neposit.

The track of the Quincy Railroad was supported on stone sleepers eight feet apart. Resting on these were 6 inches by 12 inches wooden rails on edge. Iron plates three inches wide and one quarter inch thick were fastened to the top of these wooden rails by means of spikes. At public road crossings stone rails were substituted for the wooden ones, and large iron plates were firmly bolted to the stone. This road continued in service for more than a quarter of a century with little expenditure for repairs.

W. Hasell Wilson, principal assistant engineer on the construction of the Philadelphia & Columbia Railroad under the direction of his father, Major John Wilson, who was chief engineer, kept a notebook and diary which describes in detail the nature and the costs of the methods adopted in the construction of that road. Part of the road was laid with granite sills and part with wooden sills. The granite sills were not less than three feet long and one foot square, or contained not less than one square foot of cross section. Eight inches was the minimum depth permitted. They were made as nearly square as possible with the bed and upper surface parallel. The upper surface was dressed for five or six inches to afford a smooth bearing for the iron. The ends were dressed square so as to be in contact for at least three inches in depth below the rail and for six inches below the stone, exclusive of chamfering.

Broken stone, having a maximum size of two inches, clear out of earth, clay or other material, was placed in well compacted layers not less than three inches deep. The sills were then laid and bedded with a heavy rammer. After the sills were placed holes were drilled to correspond with the holes on the bars and to suit the width and position of the track. These holes were 3 1/2 inches deep, 5/8 of an inch in diameter, and no hole was permitted closer than three inches to the edge of the sill. They were then filled with plugs of seasoned locust made to fit the hole exactly so as to require little driving. The bars were then laid and the inner edge of the sill chamfered off two inches wide and one and one-half inches deep.

The horse path was filled in, and the earth sloped from the back of the sills, to drain off the water which might collect on the surface.

The iron bars (rails) were 15 feet long, 2 1/4 inches wide, and 5/8 of an inch thick. The spikes were 3 1/2 inches long, 3/8 of an inch square, with heads fitting the countersink of the bar.

In another form of track wooden rails were used with the wood sills (ties) of chestnut, white oak or chestnut oak. These were 7 1/2 feet long and 7 inches square, resting flat on the underside and notched on the top. The wood rail was yellow pine, six inches square. Keys were white oak or yellow pine, one foot long, 2 inches by 1 1/2 inches tapering to 3/4 of an inch.

Between Broad street, Philadelphia, and the Schuylkill river the construction consisted of edge rails on stone blocks and stone sills. The blocks were of granite 20 inches by 16 inches by 12 inches deep. The transverse sills (ties) were of granite 6 1/2 feet long and 12 inches square. These were placed at the joints in the rails, about 15 feet center to center.

In laying the track broken stone in well compacted layers three inches deep supplied the foundation for the blocks

and sills. These were drilled, the chairs fastened on, and the rails placed and keyed. Broken stone was then rammed around the blocks and sills and the horse path filled in. The rail weighed 41 1/4 pounds to the yard. Between the chair and the block a piece of canvas, which had been soaked in tar, was inserted. These three types of construction cost $10 179.20, $5 604.48 and $12 568.85 to the mile. Where the latter type of track was laid without stone sills the cost was $10 927.88.

Several other variations of these types were used and cost approximately $13 000 for a mile of track.

The word « sills » was used usually to indicate wood or stone which performed functions similar to those now entrusted to ties, although sometimes it was used to indicate a continuous foundation on which the rails were laid. The relatively small number of ties used will be noted. This indicates that, at this time, danger of spreading track was not fully realized. It is a little surprising to note, also how nearly one of the systems adopted approximated modern methods in creating a foundation of broken stone and using wooden ties.

Snake head rails.

At this period practically all of the railroad tracks consisted of bars of iron spiked on continuous stringers of wood. No joint fastenings were used with this type of construction. As a result, « snake heads » became one of the recognized and most important perils of railway travel. It was not uncommon for one of the iron bars to become loosened from its fastenings and, as the train moved over it, it would suddenly turn upward at the end and pierce the bottom of the cars, occasionally derailing the train or injuring a passenger.

Horatio Allen, chief engineer of the South Carolina Railroad, which had ten miles of road in operation in 1830, 52 miles in 1832 and 75 miles in 1833, and who was the first to use a locomotive of American construction, says, « This was the age of wooden rails capped with iron. Confidence and capital had not yet reached the growth to make an iron track of the most modest weight per yard. Steel rails were as unthought of as telegraph. On timber rails 6 inches by 12 inches iron bars 2 1/2 inches by 1/2 inch were spiked. The wood used for the rails was Southern pine, the hard, resinous surface of which was as suitable for the iron bars wood could be. »

Iron rails come into use

The South Carolina Railroad was one of the first to substitute edge or iron rails for bars over its entire line. Desire to use iron rails was very general, but the difference in cost of construction was about $6 000 a mile and this outlay was too great to be borne by most of the early companies. For this reason flat bars continued to supply the iron for most of the roads up to the end of the fourth decade. In 1839 all the New York railways, except the Long Island Railroad, used flat bars. All the railways in Pennsylvania used iron plates or bars except the state railways. The Norristown line, at that time, used a 40 lb. rail; the Philadelphia & Reading a 45 lb. rail. All the railways of Virginia, North and South Carolina, Georgia and Florida used flat bars except the South Carolina Railroad and a portion of the Georgia Railroad and the Central Railway of Georgia. All the railways in Alabama, Louisiana, Mississippi, Tennessee and Kentucky used flat bars except the Pontchartrain of New Orleans, the Mississippi Railroad, the Vicksburg & Jackson Railway, and the Grand Gulf & Port Gibson Railroad. All the railroads in the western states used iron bars and plates except the Madison & Indianapolis.

The imperfections of the snake head rails and their early English substitutes suggested to Robert L. Stevens of Hobo-

ken, son of Colonel John Stevens a prominent early advocate of railways, an improvement in rail design which is the progenitor of the present T-rail. While on board ship, bound for Europe to order the « John Bull, » in 1830, he worked out a design which he thought would be an improvement. The best rail then known was the T-rail without a base. Owing to its peculiar shape it required a chair on every cross bar or stone block. Stevens' rail substantially followed this design except it was made with a base so that it could be spiked with hookheaded spikes directly to the bearing. Rails of this design were laid on the Camden & Amboy Railroad at the time of its construction, and methods of joining or splicing the rails represented a great advance in the system generally prevailing. Mr. Stevens encountered great difficulty in his efforts to induce a British rail mill to make rails of this pattern. He was obliged to assume the whole responsibility of the scheme, to pay all the extra expenses, to give heavy security against all description of damages to the works that might be inflicted by his innovation.

Recognition of the usefulness of the improvement was comparatively rapid as by 1840 this type of rail was in use on a large number of American lines. In a description of the Camden & Amboy Railroad in George W. Smith's appendix to Wood's treatise, published in 1832, the following comment appears : « The rails are of rolled iron, 16 feet long, 2 1/8 inches wide on the top, 3 1/4 inches at the bottom, 3 1/2 inches deep, the neck 1/2 inch thick. The weight is 209 lb. or 39 3/16 lb. per yard. They are secured by clamps of iron riveted at the extremity of each bar. The rails are attached to the stone blocks and sleepers by means of nails or pins at the sides driven into wooden plugs and *chairs* are dispensed with. »

The plan of constructing railways on the stone sills was adopted from the system in use in England. This type of construction led to a serious derangement of the tracks and materially increased some of the difficulties of early railroad operations. Frost under the track broke many of the solid foundations and the position of others was shifted so that a new system of construction became necessary. All of the early devices were unsatisfactory but the stone, from which so much had been expected, proved less so than the supporting wooden rails or stringers which quickly decayed or wore out.

The flat iron bars on a large proportion of the mileage of that day supplied a fruitful source of anxiety and danger and caused delays and accidents, some of which were decidedly serious. Every train carried a sledge hammer. Whenever it passed over a loose rail or left a snake head in its wake, the train was stopped and the loose rail hammered into place. Snake heads were as prominent a feature in early railroading as snags were in steamboat operations on the western rivers. Sometimes a rail would fly up and come through a car and shatter it. Not infrequently passengers were injured in this way. The relative lightness of the locomotive and rolling stock, combined with the imperfections of the track, made derailments common. At the outset, cars were destitute of springs, brakes or buffers and such appliances were adopted at a very slow rate.

Sharp curves were used with great frequency, particularly on lines which were to be run by horse-power. Frequently this was done through a desire to avoid the expense necessary to construct tunnels, bridges, deep cuts or high mounds (embankments). The influence of those prominent citizens who favored particular routes for promoting private interests was also an important consideration. An account of an early railroad in Kentucky says, « It is very crooked because the engineers who surveyed it

were adverse to crossing streams on bridges, so they went around the streams, alleging it was an advantage to have the roads crooked so the conductor could look back and see that his train was all right. »

The Boston & Lowell Railroad was opened for service 26 June, 1835. « It was built for eternity. » Granite cross ties supported iron edge rails. As in the case of the Baltimore & Ohio, the track was so unyielding that this type of construction was replaced with one using more elastic materials a few years later.

The construction of the Western Railroad of Massachusetts, completed in 1842, shows the abandonment of the solid construction of the Boston & Lowell. The rail was edge or flanged rail (T-rail) 3 1/2 inches high with 4 inches base, weighing 55 lb. to the yard. This is one of the earliest examples where heavier rails were used and more attention given to the construction of the roadbed. The chestnut crossties were 7 inches by 7 to 12 inches, by 7 feet. It was difficult for these early engineers to break away from the idea that longitudinal stringers were required. This entire line had hemlock stringers 8 inches by 3 inches laid under the ties. The rails were fastened down by 12 spikes to each rail length. These spikes were 9/16 inch by 5 1/2 inches and weighed 8 1/4 ounces each. At this time the joint fastening had not been divorced from the idea of a rail chair and each rail was supported at its end by a cast iron chair which also was used as a splice. These chairs weighed 10 lb. each. In preparing the subgrade soil and loam were removed to a depth of 2 1/2 feet and the excavation backfilled with gravel or sand.

The edge rails supported on chairs were decidedly superior to the older type of strap rails, but serious difficulties arose, particularly from the keys or wedges used to keep the rails in the chairs. These were coming loose constantly. On the Philadelphia & Columbia Railroad it was the custom to have track walkers on duty constantly. They were especially charged to tighten the keys used in the chairs. One man days and one man nights was assigned to each mile for this purpose. He carried a leather pouch containing keys to substitute for those lost or broken, and a long handled hammer for the purpose of tightening them.

Early rail manufacture in America.

Prior to 1844 no iron rail had been made in this country. The first cast iron rail was made in 1826 at Mauch Chunk, Pa., and cast iron rails were made in small quantities during the early period of railroad construction.

The manufacture of heavy iron rails was begun at Mt. Savage Rolling Mill, Allegheny county, Maryland, in 1844. This was the U-rail type designed to be laid on a longitudinal sill to which it was fastened by an iron wedge keyed under the sill, thus dispensing with outside fastenings. The rail weighed 42 lb. to the yard. About 500 tons of this pattern were rolled and laid on a road then under construction between Mt. Savage and Cumberland, about nine miles. Soon afterwards a heavier section weighing 52 lb. to the yard was rolled at this mill for a road under construction between Boston and Fall River.

The Montour Rolling Mill at Danville, Pa., was built in 1845 expressly to roll rails. At this mill the first T-rails made in the United States were rolled in October, 1845. The rolls with which these rails were produced were made for the Montour Iron Co. by Howard & Snyder of the Collier Iron Works at Pottsville. The rails, however, were produced at their plant in Danville. The Boston Iron Works, established in January, 1824, to manufacture cut nails, hoops, tack plates, etc., established a rail mill and, on 6 May, 1846, rolled the first T-rails in Massachusetts. Cooper N. Hewitt rolled heavier T-rails on 9 June, 1846, at Tren-

ton, N. J. The Trenton Iron Co. at Providence, R. I., rolled T-rails on 4 September, 1846, and delivered them to the Providence & Worcester Railroad. Between this time and 1848 T-rails were rolled at Phoenixville, Pa., by the Great Western Iron Works, at Brady's Bend, Pa., and at Lackawaxen Iron Works, Scranton, Pa., by the Bay State Rolling Mill in Massachusetts, the Rough & Ready Rolling Mill at Danville, Pa.

It seems strange that the T-rail should not have become generally popular until after 1845. The number of companies supplying facilities for rolling this type of rail indicates how quickly it did become popular once its use was started. All of the T-rails made in the mills mentioned were rolled with a base or flange similar to the rails now in use. Some of them, when laid, rested in chairs but the majority were laid directly on the tie as is the present practice.

An interesting phase of early rail manufacture is the gradual increase in the length of rails. The first cast rails were three feet long. This was increased to five and six feet, with the introduction of the malleable rail. About 1830, the rolled iron rail came into use and the length gradually increased to 12 and 15 feet. Prior to 1850 it is probable that few, if any, rails exceeded 18 feet. The majority of them were 15 feet long. The first 30 foot rail was rolled in the United States in 1855 but there was no current demand for rails of this length.

The weight increased as gradually as the length. The matter of length was merely a matter of opinion or convenience. Larger sections required larger outlay for track construction, and the sections increased only as the financial ability of the railroads increased.

Switches and frogs

When T-rails were substituted for edge rails the designs of the switches and frogs were changed necessarily. Different patterns and materials had been employed, the frogs being made of cast iron, and tongued switches were in use. Another device was a pivoted rail as a substitute for the frog. This was about nine feet long, pivoted at the center and held down by a bolt passing through a plate set on the tie and keyed. This furnished a fulcrum, and a sidewise movement at either end of the rail resulted in a corresponding movement at the other end. This device gave much trouble and was succeeded by the Lewis frog. Tongued switches were succeeded by stub switches and it was many years before the present form of split switch came into use. In the meantime, many modifications occurred during the transition period from the older types to those now in use.

The iron used for the rails gave much trouble. Under the light loads of the early motive power and rolling stock iron rails lasted for many years, but with the increase in axle loads even the heavier sections deteriorated rapidly. At many points rails lasted only two or three years and the maximum life was six or seven years. During this period rails were wholly unsatisfactory, whether regarded from the standpoint of finance, safety or maintenance.

Joint fastenings

In the earliest form of rail no joint fastenings were used. The first development was the rail chair. Next came a combined chair and plate to keep the rails in horizontal as well as vertical alignment. The third stage seems to have been the joint fastening used with the first T-rail already mentioned on the Camden & Amboy Railroad. Finally the fish plate was introduced, and this was a great improvement, the basic principle of which is still in use.

Finally the most important development made in track construction since the substitution of rolled iron rails for the old cast iron plates was the introduction of steel as a material for making

rails. The first steel rails were cast, 500 tons having been purchased and used on the London & Northwestern in England. A test begun at Camden 2 May, 1862, showed that the life of the cast rails, up to the middle of 1865, had been such that only one face of the steel rails had yet been in service although they had worn out 17 faces of the iron rails. At that time it was estimated that the first face of the steel rails were good enough to last out six more faces of the iron rails. It is, of course, understood that these were the English double headed rails which, when one face is worn, is turned and the other face placed in service.

The first steel rail rolled in America was made at the Chicago Rolling Mill under the direction of W. F. Durfee on 1 May, 1865. The ingots from which these rails were rolled had previously been cast at the Wyandotte Rolling Mill, Wyandotte, Mich. The Kelly process, an American invention which conflicted with the Bessemer patent, was used in preparation of the steel. At that time steel rails cost $166.00 a gross ton and a duty of 45 % ad valorum was imposed on rails of foreign manufacture. This price steadily decreased until 1873 when $120.50 was charged. In 1874 the cost per ton had dropped to $94.25, and subsequently steadily decreased until, in 1886, the price was $34.50.

After the introduction of iron rails and wooden crossties there never has been any deviation from the fundamental design of track construction. Notable advances in almost every detail have been made and the heavy track construction of today bears little resemblance to its early prototype. Yet, the fundamental principle of the early track still remains. Up to 1900 there were no standards. Ties, rails, ballast, joint fastenings and other track appliances were designed according to the ideas of the individual. In 1900 the American Railway Engineering Association was formed and in the 26 years of its existence it has done much to standardize engineering and maintenance practice on the roads. The great multitude of rail sections are being discarded and the few standard sections, either of this association, the American Railway Association or the American Society of Civil Engineers, are in common use. The prospect is that in a few years' time the sections of the American Railway Engineering Association will be all that survive. While various types of joint fastenings are still manufactured they are, in a large measure, being made to conform to certain accepted standards. The same is true of many other track devices, including tools.

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A summary of developments in locomotive building,

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EDITOR, MECHANICAL DEPARTMENT

Figs. 1 to 29, pp. 30 to 41.

(From the *Railway Review*.)

It seems that for a period the development of a road engine or locomotive from the stationary steam engine would be as slow a process as was the steam

engine in rising from the experimental stage. Schemes for the development of inland transportation were rife in Great Britain at the beginning of the 19th century but most of them were impracticable, although there were numerous tramways in use connected with mines. Engineers of that time did not recognize that the mining railroads might form the nucleus of a transportation system. The first suggestion on record for the construction of a railroad to carry merchandise was made before the Literary and Philosophical Society of Newcastle by one Thomas Denton in February, 1800. Two years later Richard Edgeworth suggested that the railroad scheme should be extended for the carrying of passengers. The proposal that roads with iron rails should be made to carry steam engines as motive power gradually found favor among engineers of that time, but the idea of changing the methods of transportation was intensely repellant to narrow prejudice and prevailing ignorance.

At what appeared to be the end of the period when the inventing of a practical, self propelled steam engine seemed beyond the power of European engineers, an American suceeded in performing the work. This was done by Oliver Evans, a native of Delaware, who, as early as 1786, applied to the legislature of Pennsylvania for a patent on a high-pressure steam engine. The patent was refused, but Evans proceeded to build high-pressure steam engines which were used for driving mill machinery and other purposes. American inventors apparently were much more successful than their rivals in Europe in constructing boilers that were safe under high steam pressure. European inventors, seeking to improve upon the existing type, used the domestic caldron as their model which was essentially weak. Americans, untrammeled by precedent, adopted the original idea of pipe boilers which had great pressure resisting power. Evans used steam of 150 pounds pressure and there is no record of any accident to his boilers.

Poverty prevented Evans from making a success of his high-pressure engine but he realized that it could be made to propel ships, and to drive railroad trains, and he did all in his power to make the world of his day understand the benefits of his invention. One of his early forms of self-propelled vehicles was the « Oruktor Amphibolis » which he built in 1804. It was in the form of a dredging scow weighing about 4 000 pounds, built for the city of Philadelphia. When it was ready for launching he mounted the scow upon wheels and propelled it by the steam engine through the streets of the city. This was the first power driven vehicle to operate on American soil.

The first steam locomotive designed to run upon rails was built in England in 1803 under the direction of Richard Trevithick, a Cornish mine captain, in a blacksmith shop connected with the iron works of Merthyr-Ty'dvil in South Wales. Trevithick had been experimenting for several years with a steam carriage for common roads, and there is a working model of a road locomotive made by him in 1802 preserved in the patent department of the South Kensington Museum, London. At about this time Samuel Homfray made a wager of 1 000 guineas that he could convey a load of iron a distance of nine miles by the power of steam alone, on a cast iron tramway, and Trevithick was invited to construct the engine that was to win Mr. Homfray's wager.

In 1802 Trevithick had been granted a patent for a high-pressure steam engine which contemporary writers say was an imitation of engines built by Oliver Evans for stationary engine purposes. There is a statement in Wood's « Practical Treatise on Railroads », published in 1832, to the effect that Trevithick copied Evans' designs of a high-pressure engine and used them as his

Fig. 1. — Comparison of early and present methods of railroad transportation.
The illustration shows the *Twentieth Century Limited* of the New York Central and the De Witt Clinton on parallel tracks.

own invention. Trevithick, however, devoted his attention to using the engine for land transportation, and he made an engine in 1803 which, in February of the following year, conveyed ten tons of iron a distance of nine miles, thus winning the wager for his employer.

After the first apparently practical design of steam engine had been invented it required almost half a century to develop it into a mechanism suitable for driving manufacturing machinery. Another half century had passed before inventors began seriously attempting to devise a steam engine to drive a vehicle on land. A variety of experimental locomotives had been built or patented before the end of the 18th century, but nothing of a practical nature was produced until Trevithick's engine was built. Although Trevithick abandoned the practice of locomotive building after his first attempt, the influence of his work was far reaching. The fame of his achievement had reached the ears of the men who were attempting to reduce the expense of horse power for hauling heavy loads.

Trevithick's experiment resulted in considerable effort being put forth in the next ten years to improve upon his locomotive. Much attention was given to devising means to prevent the driving wheels from slipping which was a serious trouble with the Trevithick engine, due to the tractive power being much too great for the weight available for adhesion. About this time Matthew Murray, of Leeds, built some engines for J. Blenkinsop for use on tramways connected with the Middleton colliery near Leeds. These engines operated a cog wheel which engaged in a rack rail. They performed very well and some of them were maintained in service for almost 20 years.

During the period when Blenkinsop's engines were in use an enterprising engineer named Christopher Blacket was principal owner of the Wylam Colliery near Newcastle-on-Tyne. He was very anxious to use the steam engine on the tramways about the colliery. The superintendent of this colliery was William Hedley an engineer of some attainment, and the foreman of the blacksmith shop was Timothy Hackworth, who afterward became a celebrated locomotive designer and builder. Blacket had examined the Blenkinsop engines and objected to the rack rail arrangement. To test the necessity for using such an aid to traction Blacket had windlass handles applied to the axles of one of his coal wagons, and made tests which indicated that a locomotive would have sufficient adhesion to haul cars on a smooth rail. With this knowledge a locomotive was constructed by Hackworth, according to designs prepared by Hedley. All of the work was done in the blacksmith shop of the colliery. The first engine was not a success, but his experience, and a knowledge of its shortcomings, enabled Hedley to build a second engine which worked very well, and is now in the South Kensington Museum, London, bearing the name *Puffing Billy*. The engine which was built in 1813 had a return flue boiler and was capable of developing all of the steam required. This form of boiler had been used by Trevithick and was the best type of boiler used until Robert Stephenson applied a multi-tubular boiler to the *Rocket* in 1829.

The advent of the *Puffing Billy* was the beginning of another era in locomotive construction which maintained until about 1829 when the Liverpool & Manchester Railway offered a prize for the most successful locomotive. Hedley's engine was not a model of simplicity but its complications were modest to many of its successors. The pioneer locomotive builders did not realize that complicated mechanism was objectionable until sad experience with breakdowns taught them that the fewer parts used, which were liable to breakage, the more successful the engine was likely to be. They were the first engineers to

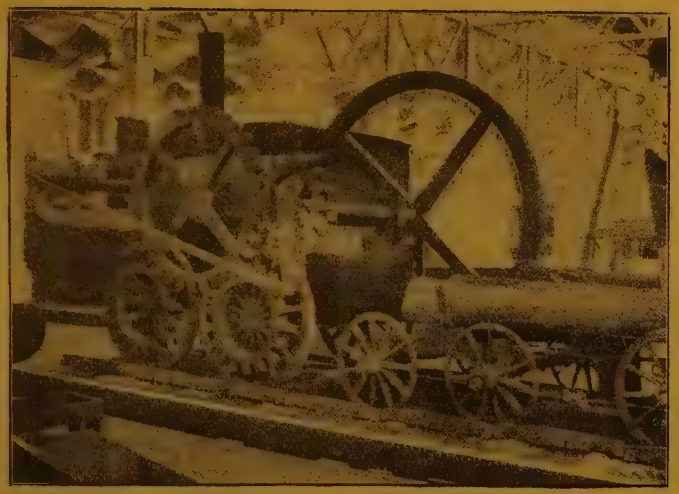

Fig. 2. — First movement by steam on rails.
The *Trevithick*, built in 1804.

Fig. 3. — *Atlantic* 1831.
One of the earlier types of locomotives built.

Fig. 4. — *Tom Thumb* 1830.

Fig. 5. — Natchez & Hamburg Railroad locomotive

Fig. 6. — *Puffing Billy* 1813. Oldest locomotive in existence.

Fig. 7. — *Old Ironsides* 1832. One of Baldwin's first locomotives.

Fig. 8. — Locomotive built for the Hudson River Railroad in 1860.

Fig. 9. — Fast passenger locomotive, Pennsylvania Railroad, 1867.

Fig. 10. — The famous locomotive *General*.

Fig. 11. — Baldwin passenger locomotive of 1880. Built for the Atlantic Coast line.

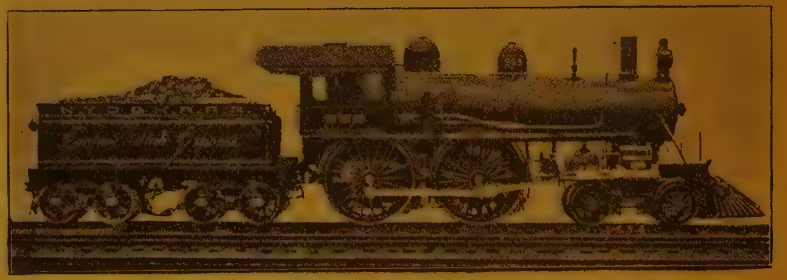

Fig. 12. — Locomotive *999* holder of the world's speed record.

Fig. 13. — Baldwin locomotive of 1896 built for the Atlantic City Railroad.

Fig. 14. — Baldwin *Santa Fe* type locomotive of 1903 built for the Atchison, Topeka & Santa Fe Railway.

learn of the destructive effects of operation over rough track.

At the time Hedley's locomotives were built, George Stephenson a mine foreman, was employed at a neighboring colliery. In 1814 he built an engine something like Hedley's but with a single flue. This experiment was almost a complete failure, but through persistent effort, and after about 20 years association with his son Robert, he eventually became the foremost locomotive builder in the world.

The years from 1803 until 1830 were a period of experiment in developing the locomotive. The history of the locomotive from the time of Trevithick's experiment until the Stephensons achieved their triumphs with the *Rocket* in 1829 presents a record of disasters, and forcibly illustrates the determined persistence which some men will devote to the practical working out of an idea in which they have confidence.

The locomotive engine was developed into a practical means of power for hauling coal on private railways connected with coal mines in the north of England. In 1825 the Stockton & Darlington Railway, a public enterprise 25 miles long, was opened and operated locomotives built by Stephensons and others. George Stephenson & Son had established locomotive building works at Newcastle, and many other firms were by this time turning their attentions to locomotive construction. The first locomotive operated on the Stockton & Darlington Railway was called « Locomotion. » The engine worked fairly well, but not any better than many others of the same period constructed by other builders.

About the time the Stockton & Darlington was opened a few leading merchants of Liverpool and Manchester organized a company to construct a railway from Liverpool to Manchester. Although there were almost 50 locomotives at work in different parts of England when the Liverpool & Manchester Railway was approaching completion in 1828, there was considerable divergence of opinion as to the proper form of power most suitable for operation on the road. Many learned consulting civil engineers of the time favored the use of stationary engines with rope traction. George Stephenson, who had been one of the constructing engineers of the road, advocated the use of steam locomotives. After several months of deliberation the directors of the company determined to try locomotives and offered a prize of £500 for an engine that would fulfill certain requirements.

Three engines entered into the contest, all of them being departures from the prevailing grasshopper types. The *Rocket,* built under the supervision of Robert Stephenson won the prize. A series of very thorough tests was made at Rainhill near Liverpool and the *Rocket* was the only engine that performed successfully without some kind of a mishap. It is reported that in a test of speed without any load the engine attained a speed of 29 1/2 miles an hour, and with a car containing 36 passengers it attained a speed of 28 miles an hour. This extraordinary speed was a startling revelation to the people who had opposed the practicability of locomotives, and did more than all previous 26 years' experience with locomotives to convince people that a new era in methods of land transport had arrived.

The *Rocket* was a four wheel engine, the front pair of wheels being the drivers, to which power was transmitted from outside cylinders set diagonally across the boiler, pointing toward the back head. The first improvement made in the next engine was to lower the cylinders to a nearly horizontal position at the side of the firebox. That was followed by placing the driving wheels behind, and locating the cylinders in the smoke box, from whence the power was transmitted to the driving wheel through a crank axle. Outside frames were also

Fig. 15. — Baldwin *Atlantic* type passenger engine of 1906.

Fig. 16. — Baldwin *Consolidated* type of 1910, built for the Pennsylvania Railroad.

Fig. 17. — Baltimore & Ohio *Santa Fe* type freight engine of 1910.

Fig. 18 — Triple articulated engine built in 1916 for the Erie Railroad.

Fig. 19. — Baldwin articulated *Mallet* locomotive built for the Baltimore & Ohio in 1919.

Fig. 20. — Two-hundred ton electric locomotive built in 1924 for the Pennsylvania Railroad.

Fig. 22. — Steam turbine locomotive built by Krupp Works in 1924.

Fig. 21. — Southern Pacific oil burning heavy duty freight locomotive built in 1922.

employed for the first time. The first of this style of locomotives was built by Stephenson, and was termed the *Planet*. It led to the construction of what was at one time called the Planet type. Many of these engines were imported into the United States and had considerable influence on the designs of early locomotives in this country, especially those engines built in New England.

The Stephensons were not the originators of the crank axle engine with cylinders in the smoke box, however, as that style was first designed by Edward Bury in 1829, but the engine was not completed until 1834. This engine or others of a similar design exercised considerable influence on later American designs. Noteworthy features of the Bury engine were inside cylinders, inside bar frame and a boiler with a hemispherical topped firebox.

In this connection it is interesting to note that agitation in favor of railroad building began in the United States about the same time as it did in England, and the machinery for operating the roads was developed largely by American engineers. There is an impression prevailing that pioneer American rairoad engineers were guided by English types of machinery, and English methods of construction, which is a fallacy. Oliver Evans, as has been stated previously, developed the high pressure, high speed engine as an improvement on Newcomen's atmospheric engine, and it was much better adapted for locomotive purposes than the ponderous slow moving locomotives that early British inventors had as examples from which to work. Americans as a rule knew very little about what Englishmen had done when they began building railroads, and most of their early locomotives were entirely original. Very little information of a practical nature had reached this country before American engineers began constructing railroads. Before the era of rairoads there was scarcely any means

Fig. 23. — One of the first coal burning locomotives operated by the Illinois Central Railroad.

Fig. 24. — Two cylinder compound locomotive with high pressure water tube boiler built for Delaware & Hudson Company.

Fig. 25. — Virginian three unit electric locomotive representing latest development in electrical construction.

of spreading scientific information, and few Englishmen really knew anything about how railroads were going to be operated when the Stockton & Darlington or the Manchester & Liverpool railways were under construction. Six months before either of these roads were opened for traffic the directors were inundated with all manner of schemes for operating them. There were plans proposed for working the roads with water power; some advocated hydrogen and others carbonic gas. Atmospheric pressure also had its advocates, while others favored cog rails. There was a multitude of counselors who proved nothing, except that the scientific men of England had no knowledge of what had been done by such men as Trevithick, Blenkinsop, Hedley, Stephenson, Hackworth and many others.

With conditions such as this in England it is not at all surprising that American engineers were called upon to develop ideas of their own conception, when they began to build railroads and

Fig. 26. — Great Northern Railway simple articulated locomotive.
This is the largest engine of its kind in use in Western Territory.

to place them in operation. They were entirely guiltless of imitating English practices when they began operating the first railroad in the world ever projected for general traffic. This road is reported by some historians as being the Baltimore & Ohio, which was chartered in 1827 and was partly opened for business in 1830, although there are others who contend that this was not the first railroad actually placed in operation in this country.

The first locomotive on the American continent that was used to run on rails was brought from England by the Delaware and Hudson Canal Co., and was tried near Honesdale. The engine was selected by Horatio Allen, a celebrated pioneer engineer, and was brought to the United States under his supervision. He acted as engineer on some of the first trials of the locomotive made in August, 1829. The engine was of the vertical cylinder type favored by early locomotive builders for hauling coal. It weighed seven tons, and was reported by Allen as being too heavy for use on trestles. This report closed the usefulness of the *Stourbridge Lion* as the engine was called. It was afterwards dismantled, and in 1905 the boiler and other parts of the locomotive were collected and sent to the Smithsonian Institute, Washington, where it was once more put together with the addition of a few new pieces making a complete engine.

This failure did not dishearten men who were advocating the construction of railroads. The first 30 years of the 19th century was a period of speculation for Americans about the probable success of railroad building, and of the utility of the locomotive. While as has been previously mentioned, the Baltimore and Ohio

Fig. 27. — Southern Pacific (4-10-2) type three cylinder passenger engine.
This is one of the latest developments in locomotive construction.

Fig. 28. — *Lima* (2-8-4) type locomotive constructed by the Lima Locomotive Works, Inc.
The latest development in simple locomotives.

Fig. 29. — Virginian (2-10-10-2) type *Mallet* articulated compound locomotive.
One of the largest locomotives in operation in the United States today.

Railroad was the first in the United States to have a section open for regular traffic, and the first railroad on which an American built locomotive did useful work, the promoters of other railroad enterprises were planning extensive railroad construction. Before the end of the year 1830, the legislatures of nearly every state in the union had granted charters for railroads.

At about the same time that the people of Baltimore were preparing to invest their capital in railroad construction, the citizens of Charleston, S. C., were attempting to establish railroad communication with Hamburg, on the western border of the state, 136 miles distant. A charter for this road was obtained in 1827, and was renewed in January, 1828. The charter was granted to the South Carolina Canal and Railroad Co., one of the first acts of the directors of this railroad was to offer a price of $500 for the best locomotive driven by horse power. The money was awarded to C. E. Detmold, who invented a horse driven vehicle operated by an endless chain platform. This apparatus carried twelve passengers and attained a speed of twelve miles per hour. A sailing car was also tried but its career was even shorter than that of one tested on the Baltimore & Ohio Railroad at about the same time. After the failure of this sailing car, Horatio Allen was appointed to the position of chief engineer of the road, and in a report to the directors, urged that a structure of sufficient strength be constructed to permit of the operation of locomotives as power. The directors met in January, 1830, and Allen's was fully endorsed. This was the most progressive action hereto taken by a board of railroad directors in this country, and the Charleston railroad was the first in the world to decide positively that the road should be operated by locomotive engines. When the South Carolina Railroad Co. decided to purchase a locomotive, the duty of selecting it was conferred upon E. L. Miller, an influential merchant of Charleston, who engaged Detmold, who was the designer of the horse driven locomotive, to design an engine to be driven by steam. Between Miller and Detmold, they produced designs for a locomotive which they guaranteed to haul a load three times its own weight, at a speed of ten miles an hour. This engine was erected in the West Point foundry, New York, and was named *Best Friend of Charleston.*

A curious thing about the design of his locomotive is that it showed a decided originality, and displayed a high order of engineering ability. *The Best Friend* was a four-wheel engine, all four wheels being drivers. It had two inclined cylinders working on a double crank inside of the frame, with the wheels outside of the frame. The wheels were connected together outside by driving rods. Iron hubs, wooden spokes and felloes, with iron tires and an iron web, and pins in the wheels to connect the outside rods were used. The boiler was vertical, in the form of a bottle, the furnace at the bottom being surrounded by water. The weight of this engine was 10 000 lb. and estimated according to our present rules, the tractive effort, with 50 pounds boiler pressure was about 400 pounds. Running at a speed of 20 miles an hour, and working steam at 75 % a stroke, the engine was capable of developing 12 H.P. This engine was taken from the West Point foundry to Charleston by boat, and was placed in operation in November, 1830.

The Best Friend was in service for about seven months, and performed very satisfactorily, except that it was necessary to reconstruct the wheels and use iron instead of wooden spokes. After this period of service, the negro fireman, who was left in charge while the engineer superintended the loading of cars, became annoyed by the noise of the safety valve, and fastened it down, with the result that the boiler exploded. The

engine was afterwards rebuilt in the shops of Thos. Dotterer, a Charleston mechanic. The work was done under the direction of Julius D. Petsch, who applied straight axles with outside cylinders, and cast iron wheels. Petsch, who had displayed so much skill in reconstructing this engine was appointed master machinist of the road, and is reported as being the first man in the world to have held that title.

At about this same time Horatio Allen designed a double ended locomotive which was called the *South Carolina.* The engine was built and placed in service, but like many other freak locomotives spent most of its time in the repair shop. When the railroad company was ready to order the fourth engine, which was in 1833, Miller went to Philadelphia and consulted M. W. Baldwin, who had built one locomotive, and was inclined to engage in the work as a regular business. These two men eventually designed a locomotive which was built by Baldwin and called the *E. L. Miller.* This engine was delivered in March, 1834, and became one of the most famous locomotives of its day. Its form of construction was standard with Baldwin until the necessity for heavy power gradually led to changes in design. When the *E. L. Miller* was placed in service, the South Carolina Railroad was the longest railroad in the world.

From that time until the present, many experiments were conducted, and numerous changes were made in locomotive designs. All manner of tests were conducted, and different types of boilers, cylinders, wheel arrangements, and driving mechanism, were tried, which gradually led to the almost general adoption of practically the same form of locomotive construction as is in use at this time.

Following closely upon earlier developments, Baldwin introduced a four-wheel truck about 1834, although this truck had been previously used by John B. Jervis in 1831. Furthermore, Baldwin realizing the benefits to be derived from the use of high pressure steam, introduced ground metallic joints in place of canvas and red lead joints for steam pipes, thereby opening a way for those who were to follow with the use of steam of still higher pressure.

At about this same time the Norris Locomotive Works was established, and succeeded in building a locomotive of the same total weight as Baldwin's engine, but with greater hauling capacity. The next logical step in locomotive development was the use of two pairs of driving wheels. This was done by Henry R. Campbell in 1836, who designed the first American (4-4-0) type locomotive. This engine was constructed by James Brooks of Philadelphia, and, as it had no equalizing beams between the two pairs of driving wheels, it did not perform satisfactorily. Shortly after the introduction of four driving wheels, Baldwin conceived the idea of a flexible beam truck which enabled him to construct a locomotive having six coupled wheels. Such locomotives were placed in service in 1842, and in 1846 the design had been altered to use eight coupled drivers. About 1850 the desire for more rapid passenger service led to the introduction of large driving wheels. This practice was first incorporated by Baldwin in the *Governor Paine* built for the Central of Vermont Railroad in 1849. In 1852, James Milholland of the Philadelphia & Reading Co. constructed passenger engines having driving wheels 7 feet in diameter. *The Tiger* built in 1856 for the Pennsylvania Railroad Co. was one of the most successful passenger locomotives of that period. It used wood for fuel, and its total weight was approximately 28 tons.

During the Civil War period almost anything that would operate on wheels was acceptable, and many older types of engines were rebuilt or redesigned, and locomotive designers and builders be-

came quite as numerous as the locomotives themselves.

Shortly after the Civil War period the Laird guide was introduced, and in 1877 John E. Wootten of the Philadelphia & Reading, introduced the Wootten type boiler for burning refuse anthracite. About 1894 the desire for high speed with large trains, where great tractive power was not necessary, lead to the introduction of the *Atlantic* (4-4-2) type engines, the first of these being built for the Atlantic Coast line. Shortly after this period the increased requirements of transportation; that is, sustained high speeds with heavy trains, lead to the development of the *Pacific* (4-6-2) type which is still in general use throughout the country in passenger service. This was the first development of the *Mountain* (4-8-2) type which followed soon after.

The first so-called *Consolidation* (2-8-0) type locomotive was built by the Baldwin Locomotive Works in 1866, and was so named in honor of the consolidation of the various small roads which now comprise the Lehigh Valley system. About 1889, American locomotive designers became equally concerned in the construction of the compound locomotives. A considerable number of these engines of various types had been constructed and operated in England. Almost any single expansion type engine at the time was capable of having compound cylinders of some design applied. Among the various types in use abroad were the four cylinder *Mallet* locomotives originally designed for light service, and later built in large sizes for use in Russia. The first locomotive of this type built in the United States was used on the Baltimore & Ohio Railroad. This engine was exhibited in St. Louis in 1904, and later operated very successfully in mountain service. However, as this was a single locomotive, the type did not attract much attention or create any amount of interest among railroad men until about 1906 when James J. Hill purchased five of the engines for the Great Northern. In order to obtain the proper estimate of their value Hill placed them on one section of the road, removing all locomotives of other types. The experiment was successful and *Mallet* locomotives for steep grades and heavy traffic became popular and are still in use.

At the same time the fact that compound locomotives were economical, and gave satisfactory results so far as fuel and water consumption were concerned, and the constantly increasing size of locomotives made the use of compound cylinders more and more difficult. With the introduction of superheated steam at about this time locomotive designers were enabled to produce simple engines of almost equal efficiency. This permitted the builders to enlarge the size of the units, and to increase their power and yet maintain a satisfactory performance. It should be mentioned in this connection that at about this same time *Mountain* (4-8-2) and *Santa Fe* (2-10-2) locomotives were introduced. In both these types the trailing truck principle which originated in the *Atlantic* type engine was used for the purpose of providing increased boiler capacity.

No further noticeable changes were made in the general types of locomotive construction until the Railway Administration attempted to standardize designs. This brought about a better consideration of design, and has resulted in a much greater interchange of ideas among motive power men than could have been obtained in any other manner, and while none of the classes or types of locomotives developed were radically different from others in use, this attempted standardization, no doubt, greatly improved locomotive construction.

At the present time, locomotives have practically reached a limit in size, because of restrictions in clearances and allowable loads on track. And now it

remains to further improve design and coordinate those features which are known to produce more efficient and economical operation. At present there are locomotives under construction or in operation using unusually high boiler working pressures. The re-introduction of the three cylinder principle, and its practical application, is another step toward improvement. Automatic cut-off control has its possibilities in improving operation. Feed water heaters, syphons, brick arches and improved draft appliances are lending their part to more efficient locomotives.

Aside from developments in the conventional types of locomotives, mention may be made that steam turbine locomotives have been constructed which show considerable economy in operation. The Diesel locomotive, while yet in the experimental stage, is worthy of notice, as are the many improvements in the electrically operated units. While the general trend in locomotive construction at this time is toward more efficient engines, it is believed that the first demand is for the perfection or improvement of locomotives along general lines of the present successful designs. Some advocate substitutes for the present steam locomotive, but it will appear in so far as past practices have shown that the only logical substitute for the locomotive of to-day is an improved locomotive of refined design.

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Work on Moffat tunnel now in full progress.

Figs. 1 to 6, pp. 47 and 51.

(*Railway Age.*)

The completion of headings in the Moffat tunnel for nearly one-third of its total length of 6.1 miles during the first 12 months of actual construction affords reasonable assurance that this remarkable project will be completed within the estimated construction period. Thus the dream of the late David H. Moffat of an effective rail route from Denver into the interior of northwestern Colorado, with the vision of its eventual extension to Salt Lake City, as an important link in a transcontinental railroad, is assuming more nearly the aspect of reality than at any time since he first undertook the construction of what is now the Denver & Salt Lake Railway.

That the tunnel through the continental divide was the key to the success of this road was thoroughly recognized by Moffat at the very outset, but he died in 1911 while striving in vain to raise the necessary funds to carry out this essential feature of his plan. As a result, the railroad has had to struggle ineffectively for 17 years to conduct a transportation business in the face of physical obstacles such as confront no other road in this country. The road was built to a ruling grade of 2 % except for the 30-mile « temporary » line over Rollins pass, which was constructed in lieu of the tunnel. This summit crossing not only embodies 4 % grades, an exceedingly tortuous alinement and a climb to elevation 11 660, or 2 420 feet above the highest elevation attained in the tunnel crossing, but it also subjects the railroad to winter weather with extreme cold, heavy snowfall and frequent blizzards for al-

most eight months of the year. Therefore, added to the great cost of handling trains on a grade that requires four locomotives for 22 cars, there is the enormous expense incurred in fighting snow which with the other maintenance costs consumes about 40 % of the total outlay for the operation of the property. It is small wonder that the road has been beset with financial difficulties, and that the construction of the tunnel, which would have eliminated many of the railroad's troubles and resulted in a great reduction in operating expenses, lay entirely beyond the ability of the railroad because its credit was exhausted.

Repeated efforts were made to finance project.

Actual construction has come about only after years of effort to develop some practical plan for raising the necessary capital. Private financing having proved impotent, attention was directed toward the application of public credit, first, that of the City of Denver and later that of the State of Colorado, but in each case the efforts were unsuccessful. Constitutional restrictions in the one case and lack of statewide interest in the other were the stumbling blocks. Ultimate success was attained through resort to a procedure frequently followed in financing public improvements. It involved the creation of a « tunnel district » embracing that portion of the state presumed to derive benefits from the completion of a tunnel, with a tunnel commission clothed with authority to issue bonds and construct a tunnel and to levy taxes on the property within the district as a means of guaranteeing the payment of interest on the bonds and set up a sinking fund for their retirement.

While unquestionably the greatest economic benefit of the tunnel will be derived from its use as a railroad tunnel, construction has been undertaken without any definite arrangement for such use. This must be brought about by lease as the result of negociation. Under the law, however, the tunnel can not be leased for railroad use exclusively. Provision must be made also for the transportation of highway vehicles, electric current and water, the last named to be conducted through a separate bore designated as the water tunnel built alongside the railroad tunnel.

The tunnel will be 6.1 miles long, this being the shortest possible distance in which the crossing can be made at the point of closest proximity of the canyons of South Boulder creek and the Fraser river, on the east and west slopes respectively without exceeding the ruling grade of 2 % on the east approach. Connections to the existing line of the Denver & Salt Lake will require the construction of a one-mile approach on a 2 % grade at the east end and a two-mile approach on 2 % and 0.9 % grades on the west end. The base of tie at the west portal is at elevation 9 085 feet or about 113 feet lower than at the east portal. Consequently the 0.9 % approach grade is continued into the tunnel from the west portal, while the grade from the east portal is 0.3 % upward to insure adequate drainage during construction.

Tunnel built for single track.

The railroad tunnel will have a clear width of 16 feet to a height of 16 feet above subgrade, above which it will be finished with a semi-circular roof of 8-feet radius, thus giving a clear height at the center of 24 feet above sub-grade. The water tunnel is to be 8 feet square or of other dimensions affording an equivalent cross sectional area. The distance center to center of the two bores is 75 feet.

The tunnel is being built by Hitchcock and Tinkler, Inc., Denver, Colo., under a fixed fee form of contract, which provides for the division of any savings in the cost under an upset price of approximately $5 250 000, the exact amount depending on the actual quantities involved.

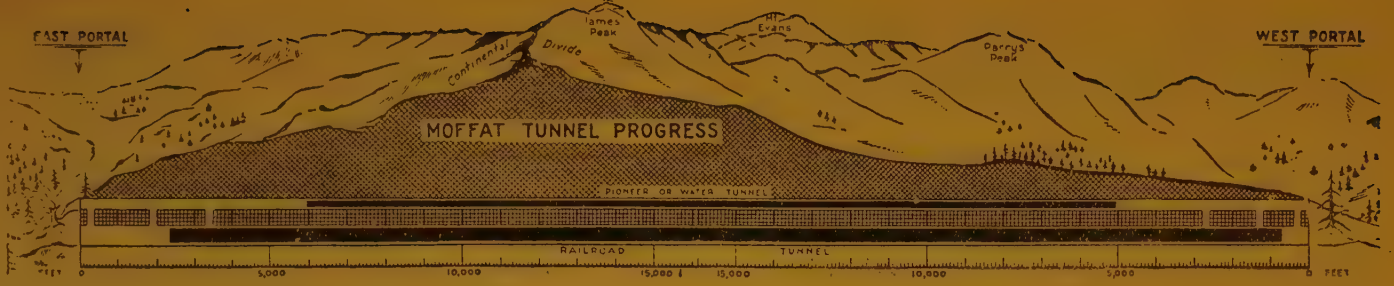

Fig. 1. — Cross section of the tunnel, showing progress to date.

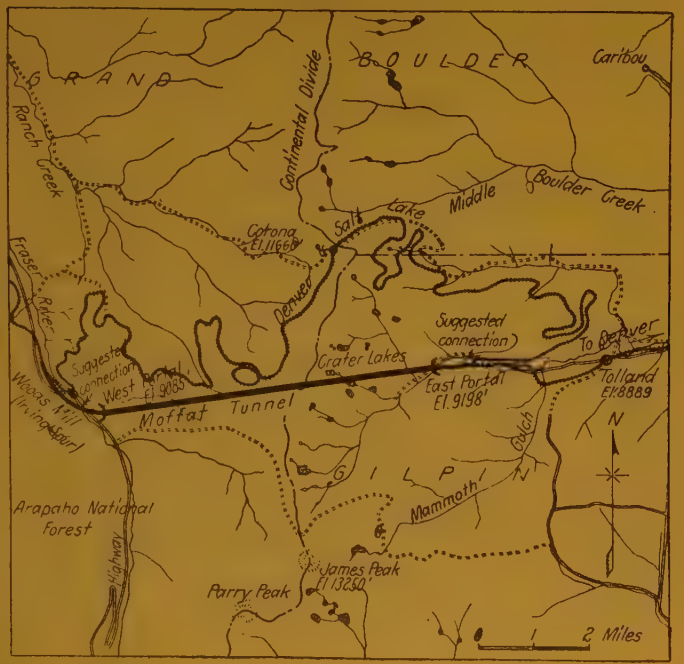

Fig. 2. — The tunnel will shorten the line 24 miles.

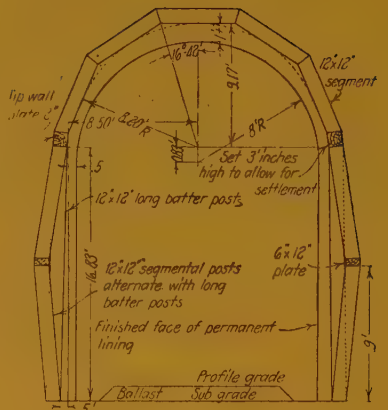

Fig. 3. — Timbering used with sub-bench method of excavation. Long posts not set until second lift is taken out.

While the distance between the portals through the tunnel will be only six miles, communication between the portals is to be had only via the slow railway trip of 30 miles over the summit or a ride of 75 miles by the shortest highway route. For this reason it was necessary to create complete and entirely independent construction organizations for the conduct of the work at each end of the tunnel.

The distinctive feature of the tunneling method is the simultaneous driving of two parallel headings 75 feet apart center to center, one being enlarged subsequently to form the railroad tunnel and the other to serve eventually as the water tunnel. Cross cuts at intervals of approximately 1 500 feet afford the necessary means of communication between the two headings. The prime advantage of the twin heading method arises from the means it affords for the conduct of the heading operations, especially the removal of the muck, without any interference with the work of enlarging the railroad tunnel; consequently both operations can be conducted more rapidly and economically. The method has the further advantage that in difficult ground where the necessity for timbering results in slowing up the enlargement operation it is possible to conduct this work at a number of points simultaneously by removing the muck through the cross cuts and out by way of the water tunnel. Another advantage which has been developed in the east headings of the Moffat tunnel is the opportunity it affords for the economical driving of the headings themselves. By employing only one complete tunneling gang for each shift on the two headings it has been possible to keep both the drillers and muckers busy at all times. The former drill the holes in one heading while the latter clean up the muck in the other, the two crews changing places to repeat operations as soon as they finish their work.

Conditions differ widely at two ends.

The Moffat tunnel affords an excellent opportunity for a thorough test of the twin heading method because the conditions which have been encountered in driving the headings for 5 800 feet from the east portal and for 4 000 feet from the west portal are entirely different. At the east end the rock is solid and, except where veins of crushed rock have been encountered at fault planes, no trouble has been experienced with unsound rock and only a very small amount of timbering has been required. On the other hand, at the west end, the rock, while of much the same general character, biotite granite gneiss, has been so badly crushed and distorted by geologic action that heavy timbering has been required for almost the entire distance that the headings have been driven thus far. As a result, the tunneling methods pursued at the two ends are entirely different, yet in each case it has been clearly demonstrated that the work is greatly expedited by the presence of a small independent heading alongside the main tunnel.

The only point of similarity in the operations is in the use of the water tunnel as the transportation route between the portals and the heading operations. A two-foot gage track in this tunnel with a switch track through the last cross cut to the other heading provides effective means for the removal of the muck in Koppel cars of 50 cubic feet capacity. The driving of the headings is followed to the last cross-cut excavated with the erection of a trolley wire carrying 250 volts direct current for the operation of four-ton General Electric trolley locomotives, while beyond the end of the trolley wire the muck cars are hauled by four-ton storage battery locomotives of the same manufacture. At the west end of the tunnel where the enlargement is conducted in a piecemeal fashion, a large

part of the muck from this operation is removed by this same equipment by way of the water tunnel.

Owing to the difference in the methods followed at the two ends of the tunnel, it is necessary to consider them independently, and as those at the east end are much simpler, they will be described first.

How the east headings are being driven.

The heading crew for each of three eight-hour shifts consists of 15 men — a shift boss, 4 drillers, 2 helpers and a nipper — who do the drilling and blasting in one heading, while the mucking force, embracing a mucking machine operator, 3 muckers, a motor man, a brakeman and a scaler, are removing the muck in the other heading. The drilling is done entirely from a carriage which consists of an approximately horizontal boom mounted on a truck by means of which it is quickly transferred from one heading to the other. On the boom is mounted a trolley which supports a cross bar 4 1/2 inches in diameter, to which, in turn, four arms may be attached at any point in its length for the support of four Ingersoll-Rand drills of special design. At the rear of the carriage is a lubricator of two gallons capacity which feeds oil to the drills through the air hose.

Each advance of the heading requires the drilling of 26 holes 8 1/2 feet long, arranged as shown in the diagram. The drilling of each hole requires the use of four bits in the following order; 2 1/2 inch diameter 3 feet long, 2 1/8 inch diameter 5 feet long, 2 inch diameter 7 feet long, and 1 7/8 inch diameter 9 feet long. In general each bit is used only once before it is returned to the shop for resharpening.

The normal charge for a round is from 150 to 175 lb. of 60 % gelatin, although 40 % explosive is used occasionally in the softer rock. Effective results in the blasting of a heading where the block of material to be removed is enclosed on all but one side, require that a wedge of rock to the full depth of the cut must be released from the center before the material at the top, bottom and sides can be moved. This requirement is met by drilling eight holes (cut holes) at an angle so as to enclose a wedge of rock in the center of the heading and loading these eight holes for direct firing, while delay exploders are used for the remaining holes so that the detonation of the charges will occur in a predetermined order. Owing to frequent changes in the nature of the rock, the charges, order of firing and arrangement of holes are subject to considerable variation.

Power equipment for mucking.

One of the most important items contributing to economy and rapid progress in driving the headings is the use of an ingenious mechanical mucker built by the Conveying-Weighing Company of St. Louis, Mo. This consists of a heavy motor-driven car equipped with an apron or scoop at its front end that is driven into the muck pile by propelling the car forward on the track. The apron is designed to swivel about a vertical axis so that it can reach both sides of the heading. The muck picked up on the apron is discharged onto a conveyor belt by swinging or folding it upward. The conveyor extends back over the top of the machine and discharges into a muck car placed at the rear. These machines have proven thoroughly effective and stand up well under the severe service to which they are subjected. Under favorable circumstances, each heading shift will complete two rounds or a total of six rounds for the three shifts in the 24 hours. This represents an approximate advance of 48 feet for the two headings or 24 feet for each heading.

In the east entry of the railroad tunnel, where the rock is stable, the enlar-

gement of the railroad heading is made in one operation by the blasting of rings of holes radiating from approximately the center of the heading to the neat lines of the full tunnel section, these rings being spaced 4 feet center to center in the longitudinal direction. The muck is loaded in 4 yard, 3 foot gage, side-dump cars by an air-operated Osgood shovel mounted on 3 foot gage trucks. The shovel has a one-yard dipper and is narrow enough to give ample space alongside for the loading of the cars, handled entirely in this case by electric trolley locomotives.

Under the normal procedure the empty cars are delivered on the shovel track directly behind the shovel and under an air operated derrick erected on the rear end of the shovel. This derrick lifts the empties one at a time as needed from the shovel track to the loading track. A second locomotive on the loading track takes care of the loaded cars. After a car is loaded opposite the front end of the shovel, it is pulled away far enough to allow an empty to be swung over from the shovel track to the loading track, which empty car is then pushed into loading position by the second locomotive. The loads are pulled in trains of 7 to 15 cars. Two shifts of eight hours each will readily remove the muck for 28 feet of tunnel or at a rate that will insure progress equal to that in the headings.

The ring holes for the enlargement are drilled from a horizontal bar set up at about mid-height of the heading, using two drills, a Denver 74-W stopper drill for the upper holes and an Ingersoll-Rand R-72 drill for the lower holes. The proper procedure for the blasting has been the subject of much study. While the methods pursued have resulted in satisfactory progress, the manner in which the muck is disposed by the blast is not always such as to effect the best co-ordination of the shooting and mucking operations. Attempts to shoot the holes in complete rings gave unsatisfactory results because considerable of the muck was thrown back into the heading and covered up the holes of the succeeding rings. This led to the adoption of the plan now followed of blasting the top and bottom holes separately, the lower holes being fired some four or more rings in advance of the upper holes. This gives a much more satisfactory disposition of the muck and approaches more nearly the ideal arrangement under which the muck pile nearly fills the entire tunnel section at all times and protects the shovel from the flying rock of subsequent blasts. The normal charge for each ring of holes is about 106 lb. of explosive.

Headings at west end present many problems.

As mentioned briefly above, the unstable nature of the rock encountered in the west end of the tunnel has given rise to methods entirely different from those followed at the east end. Moreover, it has been necessary to modify the procedure from time to time to meet the changing conditions as they were presented and to adopt a diversity of expedients as emergencies were encountered. The following is therefore but a general outline of the more common of the methods followed.

Owing to the fact that it has been necessary, with but few exceptions, to support the rock by timbering as rapidly as the headings are excavated, the heading gangs had to be organized to install the timbering as well as to do the drilling, shooting and mucking. This made it desirable to restrict each crew to a single heading instead of alternating from one heading to the other as at the east end. Therefore, to reduce the dead time of the drillers to a minimum while the muck was being removed, an arrangement of the drill holes was adopted which enables the drillers to cut all but four holes while working from the top of the muck pile after it has been leveled

Fig. 4. – Drill carriage mounting four drills ready to be set in position in main heading.

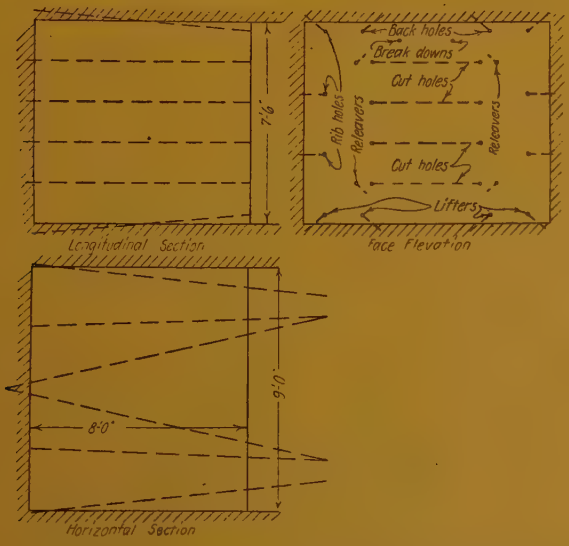

Fig. 5. — The location of typical drilling in east portal.

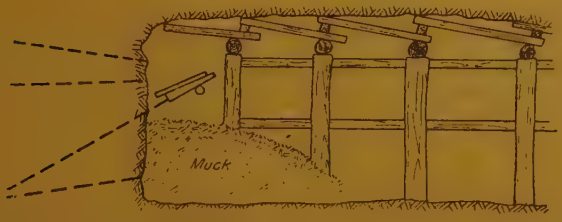

Fig. 6. — Sketch showing how holes are drilled before muck is removed in timbered headings.

to about the mid-height of the heading.

As the softer rock requires only from 14 to 16 holes, from 10 to 12 of which are drilled before the muck is taken out, only two drills are used. They are operated from a horizontal bar set at about two-thirds of the height of the heading. The bottom four holes drilled from this position are pitched at a sharp downward angle so as to reach practically to the bottom of the heading, these four holes together with four others drilled close to the bottom after the muck has been cleaned out comprising the « cut » holes which are fired direct while the holes above are exploded with delay exploders. The muck is removed with the mucking machine as in the east headings.

The timbering for the headings consists of bents of round timber obtained locally, each bent consisting of a cap and two posts. The spacing of bents varies with conditions but averages about 4 feet. The bents serve as the support for spiles or poling boards which are driven toward the face and cantilevered forward and upward from the last bent placed to support the roof until the cap for the next bent forward can be set. The cap is supported by cantilever beams swung below the caps of the bent previously set until enough muck has been removed to permit the placing of posts. Longitudinal struts set between the posts add stability to the system and afford security against displacement during blasts.

To meet the problem of enlarging the railroad tunnel under the conditions encountered, the center heading is sloped up from each cross cut so that it becomes a top center heading with the roof at a sufficient elevation to clear the permanent arch timbers for the completed tunnel section. The enlargement has been carried out according to a variety of methods and studies for the development of still further plans are under way. However, the initial step — that of widening the heading to place the arch timbers — has been carried out in the same general manner throughout all of the enlargement work. The first step is to excavate to full width on both sides of the heading. In some cases this requires the placing of temporary or false arch timbers placed in an inclined position against the ends of the caps. In other cases the rock will stand at the sides until the permanent arch timbers can be set.

After the excavation to full width has been completed, the arch wall plates are carefully set to line and grade on each side, being blocked up on short blocks or pile stubs. The arch sets consist of either three or five segments of 12-inch by 12-inch timbers spaced from 2 to 4 feet center to center. They are backed by 4-inch lagging and the space between the lagging and the rock is packed with cord wood or selected rock. The posts of the heading timbering are cut off and removed as the arches are placed but the roof timbering remains in place, care being taken to wedge up between the permanent arches and the caps of the heading sets.

Enlargement plans were revised.

The original plan and one which was followed for several 100 feet of the enlargement was to remove the entire bench in one operation, using the air shovel for mucking, exactly as in the east end of the tunnel. This plan necessitated the employment of an ingenious needle beam rig to support the wall plates while the rock was being excavated underneath them for the purpose of setting the wall posts. However, when heavier ground was encountered this plan had to be abandoned as the side pressure became so great as to bend the 12-inch by 12-inch posts even where spaced 2 feet center to center.

This led to the decision to take the bench out in two cuts of approximately 8 feet each and to the development of

a design of side timbering that not only lends itself to the two-stage plan of taking out the bench but also affords a much stronger construction to resist side pressure. As shown in the cross section of the arch the side wall construction consists of alternate full length posts and trussed posts formed by battering two half-length posts outward from the top and bottom respectively with a 6-inch by 12-inch sub-plate between them at mid-height. After the upper sub-bench has been excavated and the wall plate of the arch is supported by temporary timbering, the upper set of batter posts is set in place on the 6-inch by 12-inch sub wall-plate, a batter post being set under every other arch while the intermediate arch is carried by a temporary plumb post. When the second sub-bench is removed these temporary posts will be replaced by the permanent full length posts and the lower set of batter posts inserted between them. The side wall construction is lagged and packed as the work proceeds and the result is a timbering system of substantially elliptical section much better adapted to resist the side thrust than a wall with only full length vertical posts.

This plan of operation precludes the use of the power shovel for all mucking except that for the second sub-bench, and thus far all muck from the arch and upper sub-bench has been loaded into cars by hand, hauling it out through the cross cuts and the water tunnel or carrying it to the end of the bench and dumping it into cars on the lower level.

The enlargement process is necessarily slow but by carrying on the work from several of the cross cuts simultaneously it is hoped to make progress proportionate to that in the headings.

The power plants

The power plants and other service facilities at the two portals are similar. Both plants are operated almost entirely by electricity from a 44 000-volt transmission line, built especially to supply power for the tunnel operations. This current is stepped down to 2 300 volts for the operation of the larger machines and converted by a motor-generator set to 250-volt direct-current for use in the trolley lines, lighting circuits, battery charging, etc. No steam plant is provided in the plant, all heating of buildings being done by hot air furnaces or stoves, with hot water heaters for service in the bunk houses, kitchens, laundry, etc.

The main features of the power facilities are the compressor plants, each of which contains four units. Thus the east portal plant is equipped with three Chicago Pneumatic Tool Company compressors with 20 by 12 by 14 cylinders and a rated capacity of 1 140 cubic feet of free air each and one Ingersoll-Rand compressor with 7 by 13 by 10 cylinders and a rated capacity of 420 cubic feet. The equipment at the west portal is similar except that the large compressors were supplied by the Ingersoll-Rand Company.

Water is obtained by gravity from mountain streams at adequate pressure for all service, but pumps, both electric and gas-engine driven, are provided to insure against failure of supply. Adequate fire protection is assured by systems of 4-inch fire mains with well distributed hydrants with hose already attached and boxed ready for immediate use.

Drill repair shop an important feature.

Another important feature of each plant is a well appointed drill repair shop. That at the east portal is equipped with two Sullivan drill sharpeners, three distillate oil furnaces, a quenching tank and a forge for miscellaneous work. In this plant some 2 000 drill steels are resharpened and tempered daily by two shifts of six men each.

Other facilities include a machine shop, a store house, a battery charging room and repair shop for motors, a ma-

gazine having a capacity of one carload of explosive, placed at a considerable distance from the camp with smaller powder houses at the plant for the storage of a day's supply and the preparation of charges.

Careful attention was given to the matter of ventilation in the tunnel. Here again the twin headings proved of considerable advantage since the placing of bulkheads in the cross cuts made it possible to use one bore as an intake and the other as an exhaust duct. To clear the heading of gas incident to blasting, two rotary Root blowers of 3 840 cubic feet capacity per minute and a Buffalo conoid fan are installed outside a bulkhead in the water tunnel some distance to the rear of the last cross cut. The blowers are connected to 12-inch ducts leading to the ends of the two headings, while the fan discharges into the tunnel, just beyond the bulkhead. The effect of this arrangement is to drive the air from the headings out through the main tunnel, that from the water tunnel heading passing out through the forward cross cut and thence out through the main tunnel.

Camps are maintained to high standards.

The construction contract contains unusually explicit stipulations concerning the character of the construction camp and the measures to insure proper maintenance. Close conformity with these provisions has resulted in the development of a camp of exceptionally high standard. In addition to unusually well appointed bunk houses and a mess hall, the facilities at each camp include a laundry, a lavatory, locker and drying house, hospital, post office, a school for the children of the employees, and a recreation hall which houses a pool and card room and a hall used for both moving picture shows and dancing.

As soon as the work in the east headings could be put on a thoroughly systematized basis, a bonus system was established to stimulate progress. Under this plan two assistant superintendents and all men in the three heading shifts participate in premiums paid for production in excess of a base of 510 feet for each fifteen days in both headings (an average of 17 feet per day for each heading). Separate premium rates are set up for each of three groups of men, based on the relative influence which their work has on the progress made and in addition there is a sliding scale of bonus increases for increased progress as set forth in the table below.

	Bonus per foot of advance of the two headings.		
	Group I.	Group II.	Group III.
For each foot over 510 feet but less than 600 feet.	15 cents	10 cents	5 cents.
For each foot over 600 feet but less than 675 feet.	20 cents	12 cents	7 cents.
For each foot over 675 feet	30 cents	18 cents	10 cents.

An average maximum rate of progress of 25 feet per day has not been maintained for any considerable period but sufficient advances have been made to require the payment of bonuses of $30 to $40 to drillers and other Group I men for the 15-day period. Approximately 600 men are employed on the work, 250 at the east portal and 350 at the west portal.

The tunneling operations are being directed by the members of the contracting firm, F. C. Hitchcock and C. C. Tinkler. D. S. O'Rourke and William Fowler are superintendents at the east and west portals respectively. The Moffat Tunnel Commission, of which W. T. Robinson is president, maintains close supervision over the work through its chief engineer, R. H. Keays, who is assisted by C. A. Betts, office engineer, Burgis G. Coy and V. A. Kauffman, resident engineers, and a considerable engineering staff.

[621 .132.8 (.494)]

The Zoelly turbine-driven locomotive, ([1])

By H. ZOELLY, Zurich (Switzerland).

Figs. 1 to 6, pp. 56 to 62.

(From *Mechanical Engineering and Railway Age.*)

A *Mogul* type reciprocating locomotive belonging to the Swiss Federal Railways has been successfully converted into a turbine-driven condensing locomotive by Escher Wyss & Co., Zurich, Switzerland, in conjunction with the Swiss Locomotive Works, Wintherthur. The principal change, in general appearance, as compared with the original locomotive has been the replacement of the cylinders by a turbine. The original boiler, equipped with a Schmidt superheater, has been provided with a turbine-driven fan arranged in the front part of the smokebox as a substitute for the draft produced by the exhaust steam of the reciprocating engine.

The main turbines

The new locomotive was constructed for the same performance as the old one, so that the six-stage impulse Zoelly turbine for running ahead was designed to give 1 000 H. P. at the crankpin. The back-up turbine consists of a simple compound wheel and is contained in the same casing as the ahead turbine. The turbine rotor, comprising both the ahead and back-up wheels, is made out of a solid block, the blades being inserted in slots in the wheel rims. The turbine drives through a double-reduction gear (the first reduction 1 : 7 and the second 1 : 4.1), a jack-shaft carrying the crank-pins and the drive to the wheels being obtained by connecting rods.

The turbine casing with the reduction gear, intermediate shaft, jackshaft, and all bearings are mounted on a one-piece steel casing which is riveted to the locomotive frames (fig. 2). The turbine is placed in front of the boiler, its axis parallel to the locomotive axles (fig. 3).

Steam admission to the ahead or back-up turbines is controlled by valves which are operated from the enginemen's cab. For running ahead two groups of nozzles have been provided in the first guide wheel, one allowing the passage of about 11 000 lb. of steam when fully open, and the other for 4 400 lb. One or the other of the valves, or both, is fully open, according to the load. Intermediate quantities are obtained by throttling with the main governing valve. Only one valve which allows a total of 15 500 lb. of steam to pass, has been provided for running backwards. Smaller quantities are likewise obtained by throttling down with the main governing valve. The efficiency of the back-up turbine is lower than that of the ahead turbine for a locomotive usually runs ahead. Backing up is only

([1]) Abstract of a paper prepared by Dr. Zoelly for presentation before the annual meeting of the Railway Division of the American Society of Mechanical Engineers.

Fig. 1. — Standard 2-6-0 reciprocating type converted into a turbine-driven condensing locomotive by Escher Wyss & Co., and the Swiss Locomotive Works.

Fig. 2. — The turbine casing and balanced crank

provided for switching, manouvering, or for use in cases of emergency where a smaller amount of power is required.

The maximum traveling speed of the locomotive is 47 miles per hour and is limited by the type of locomotive. The driving wheels have a diameter of 60 inches. At 47 miles per hour the turbine makes 7 500 revolutions per minute. The turbine speed is of course, proportional to the traveling speed. When running ahead the back-up wheel rotates in a vacuum, as is common practice in marine propulsion. The wheel friction for the simple back-up turbine is small, and the losses are therefore insignificant.

The condensers and auxiliaries.

The steam passes in about equal quantities from the exhaust end of the turbine, in both the ahead and the back-up turbines, to condensers placed longitudinally on each side of the boiler. These condensers are water cooled and are of the surface type.

All auxiliaries of the condensing plant are driven by one small turbine which revolves at 9 000 revolutions per minute. This speed is reduced to 1 200 revolutions per minute through a reduction and bevel gearing and drives a vertical shaft carrying the circulating-water, air, and condensate pumps. The circulating pump takes water from the tender and forces it through the condensers and back again to the recooler. The air pump discharges at a pressure of about

75 lb. to a waterjet air ejector which communicates with the two condensers. It is designed so that the air in the air-separator can escape into the atmosphere and the water return to the suction side of the circulating pump.

The condensate from the condensers is led to the condensate pump, which latter discharges at about atmospheric pressure into the feed pump. The latter is placed on the side platform of the locomotive. It is a reciprocating pump running at 59 revolutions per minute and is driven through a second reduction from the auxiliary turbine. The feed pump discharges directly through a heater into the boiler.

The auxiliary turbine is a three-stage Zoelly impulse turbine connected to the condenser and receives steam at 11 lb. gage pressure. Exhaust steam is used in this turbine from a backpressure turbine which drives the ventilator of the recooler.

The forced draft fan.

Special means had to be provided for producing the firebox draft, as the exhaust steam was no longer available. The locomotive was first equipped with a forced draft for producing pressure under the grate. After a long series of tests, however, it was found necessary to change over to the suction principle.

The fan is of the centrifugal type, provided with a spiral casing, and is capable of producing a vacuum in the smokebox of 8.2 inches of water. A maximum of 280 cubic feet of flue gases can be discharged per second when running at 1 500 revolutions per minute. The fan is driven by a small turbine through a gear with a transmission ratio of 1 to 6. The turbine receives live steam and exhausts with a back pressure of about 7 lb. gage to the feedwater heater. The admission of steam to the turbine is regulated by a valve which is also operated from the enginemen's cab. The exhaust steam from the turbine which drives the fan is passed into the heater as there is a certain ratio between the quantity of feedwater and the exhaust steam from that turbine. If for some reason there should be no water in the heater and the steam could not condense, a safety valve opens a connection from the heater to the condenser. The condensate of the heater steam always escapes directly to the condenser and thus goes to the boiler along with the condensate of the main circuit.

This design lacks the advantage of the usual draft producer, *i. e.*, the proportioning of the draft to the quantity of steam required in the main turbine. This, however, can be realized on condensing locomotives by bleeding steam from the main turbine.

Air pump for the automatic air brake.

The design of the Westinghouse air pump does not quite suit the different operating conditions of the turbine locomotive as the exhaust steam is lost and cannot be used on account of the oil it contains. In future designs the natural course will be to employ a rotary pump, which can be driven by the same auxiliary turbine that drives the condensing auxiliaries, thus returning all steam to the boiler.

The boiler feedwater.

Theoretically the condensing locomotive does not need any additional water for boiler feeding, as the water in the boiler is working on a closed circuit. It is practically impossible, however, to eliminate leakage losses, loss through the steam whistle, and last but not least, loss through train heating. In order to obtain full advantage from the condensing locomotive it is essential that none other than clean soft water gets to the boiler. This can be assured in two different ways. It is possible to have a special tank for boiler feedwater on the tender, the feeding being effected by an injector as in the case of the ordinary

locomotive, or water from the cooling-water tank may be used, which should be treated before being sent to the boiler. The Krupp Company, Essen, Germany, which holds a Zoelly license, cleans the make-up water by sending it

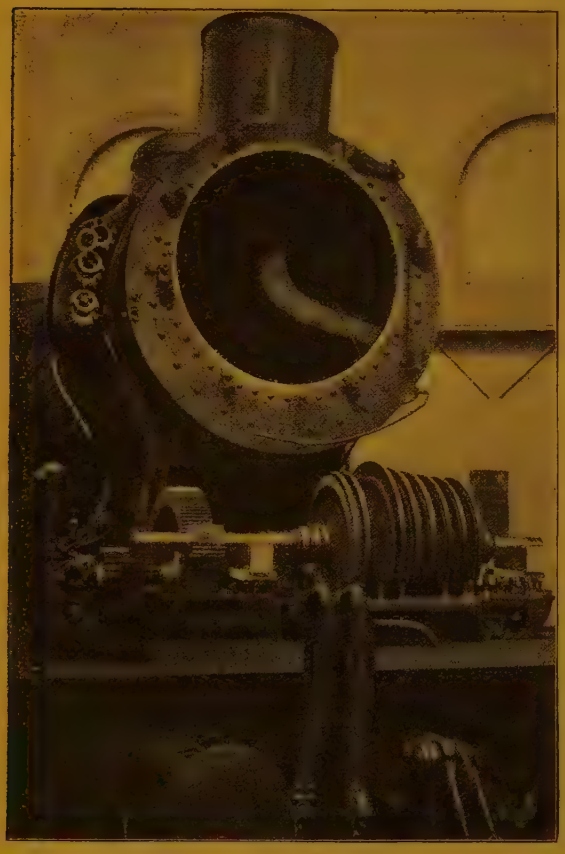

Fig. 3. — The rotor and first reduction gear of the Zoelly locomotive.

to a small evaporator. The feedwater evaporated in the evaporator escapes into the condenser, where it condenses and it is then sent to the boiler along with the condensate of the main circuit. Instead of leading the steam from the evaporator direct to the condenser, it is also possible to send it to a low-pressure turbine, or to a certain stage of the machine thus doing useful work.

Neither of these two solutions has been resorted to on the experimental locomotive. The cooling water is used direct for boiler feeding, and is fed by the steam injector when necessary.

System of lubrication and recooling.

Each turbine has its own lubricating system, comprising an oil tank and a geared pump driven from a shaft of the reduction gear. Gears and bearings are under forced lubrication, the oil for the main turbines passing through an oil cooler which is connected with the cooling-water circuit of the condensers.

The most vital part of the condensing locomotive, working with water as a refrigerating medium in the condenser, is the recooler. All the heat units taken from the steam in the condenser go to the cooling water, which of course, has to be recooled in order that it may be used in a cyclic process. The recooler (fig. 4) is a separate vehicle, taking the place of the usual tender, and it provides room for coal and make-up water for boiler feeding. It works on the vaporization principle, air being brought into intimate contact with the water to be cooled, which heats it and saturates it with water vapor. The heat to be absorbed in such manner is enormous, amounting in the case of the 1 000 H. P. experimental locomotive to about 5 760 000 British thermal units per hour, and increasing in proportion for larger locomotives.

The recooler comprises a certain number of water and air elements working in parallel. Each element consists of a wrought-iron channel of rectangular cross-section. This channel is divided diagonally into two halves in the longitudinal direction by means of perforated trays containing Raschig rings; *i. e.*, small tubes of about equal length and diameter. The water to be cooled is led

to these trays by tubes which act as sprayers, the air passing in counterflow. The cooling elements are so disposed that the natural current of air produced by the traveling train can enter the cooling element direct. A fan produces a sufficient current of air when the train is stationary or traveling at a very slow speed, and also augments the normal current when traveling at ordinary speeds. It is driven through a gear by a small back-pressure turbine, as previously mentioned. Admission of steam to the turbine is controlled by means of a valve from the enginemen's cab.

The cooled water flows from the cooling element back into a tank, whence it is again drawn into the circulating pump. As a certain amount of water is evaporated in the process it becomes necessary to add a corresponding amount in order to keep the circulating quantity constant. There is provided, for this purpose, a large storage tank on the tender, which communicates with a suction tank by means of floaters. The water in the tender need not necessarily be pure as it does not enter the boiler nor come into contact with such parts as could seriously affect the working of the plant.

Space is provided in the tender for 11 tons of coal and 1 440 gallons of water.

The recooler car and locomotive are coupled in the usual way. The connections for both the suction and discharge pipes of the cooling-water system are made by means of sliding ball-and-socket joints. These joints allow the tender to be uncoupled from the locomotive upon removing the coupling bolts. Connections for live and exhaust steam from the turbine which drives the fan of the recooler are only of small dimensions and are made by flexible pipes.

Theoretical considerations.

Recooler. — The recooler will be considered first, as the vacuum obtainable determines the calculation of the turbines and auxiliaries. The better the vacuum, the greater the total heat which can be transferred to useful work. It is known from stationary plants that with surface condensers the vacuum directly depends on the cooling-water temperature. In the case of the condensing locomotive the vacuum therefore depends upon the temperature to which the cooling water can be lowered in the recooler.

The maximum temperature that the air going through the recooler can attain is that of the warm cooling water. If it be assumed that the air at this maximum temperature is fully saturated with water vapor, then the difference in total heat between the air entering and that leaving the recooler is identical with the amount of heat withdrawn from the water. When a turbine is working against different vacua it is possible, assuming definite initial steam conditions and constant turbine efficiency, to calculate the amount of heat which has to be extracted from the steam in the condenser or, what is the same thing, from the cooling water in the recooler. If it be further assumed that the vacuum in the turbine exhaust corresponds to the water-vapor tension of water at a temperature which is 41° Fahr. higher than the cooling water leaving the condenser, we can calculate the amount of air necessary to obtain a certain vacuum for a given quantity of steam. This calculation has been made and in figure 5 curve I shows the result for cooling air at 59° Fahr. and 70 % saturated. The air necessary for cooling is delivered by a fan. Assuming constant surface area for the cooler for all the different vacua, the resistance through the cooler would of course increase with the quantity of air, and the power required for driving the fan would augment exceedingly rapidly with better vacua. These conditions are illustrated in curve II, the horsepower referring to the power necessary for each pound of steam per second. A long series of tests has shown

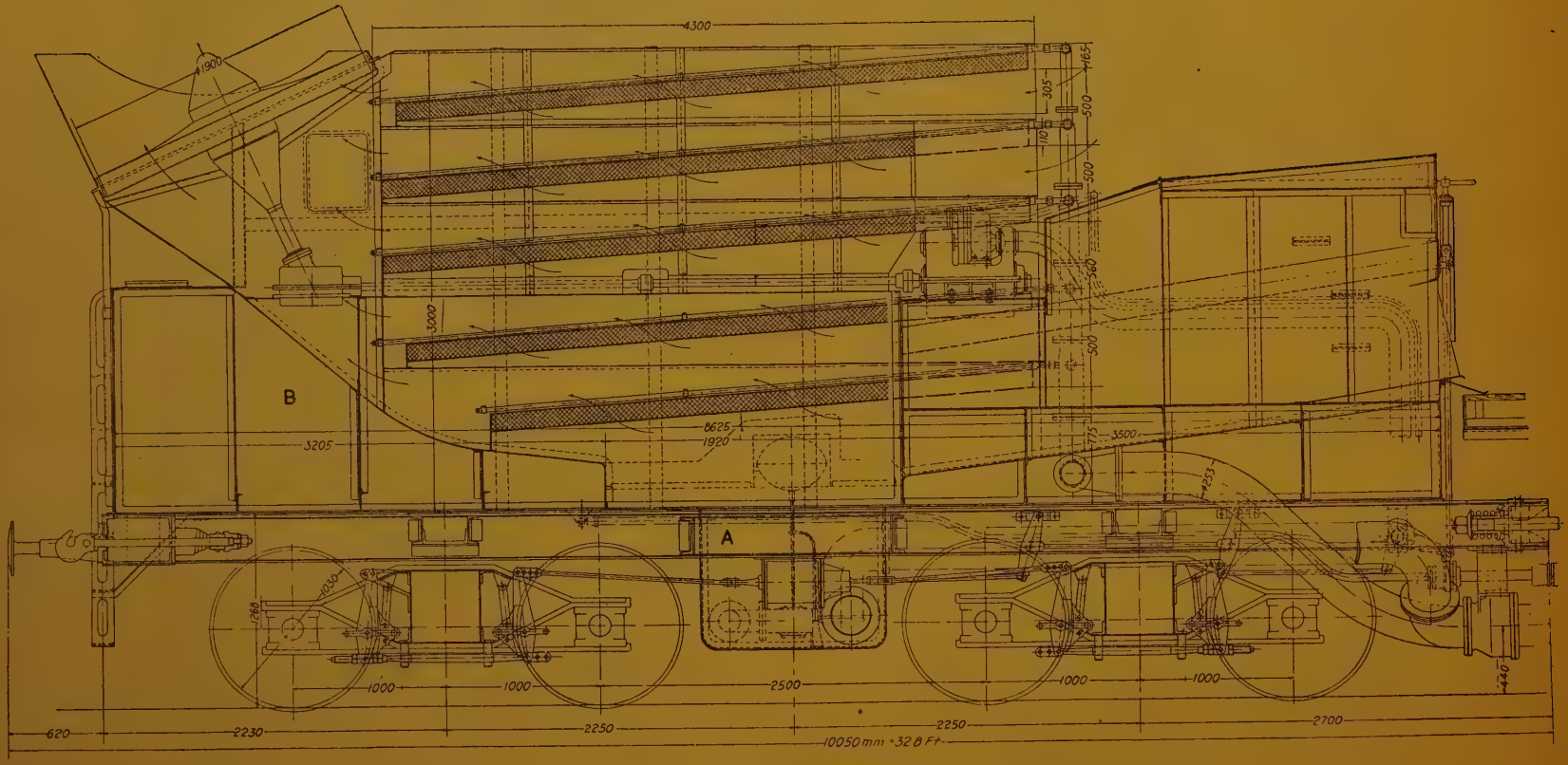

Fig. 4. — Recooler for Zoelly 1 000 H. P. turbo-locomotive (dimensions in millimetres).

that for full load the vacuum will be somewhere near 90 %, which of course would only apply to maximum loads. On partial loads the vacuum would increase on the amount of steam sent to the condenser being less.

Curve III gives the water consumption of the recooler in pounds per pound of steam.

Curves I' and II' give test results (air quantity and power absorbed by fan) which show that actual conditions do not differ materially from the theoretical.

To show the efficiency of the Zoelly cooling system as compared with that obtained by employing an air-cooled condenser, curve IV in figure 5 gives the necessary quantity of air on the assumption that the air could warm up to 122° Fahr., and curve V the power required for the fan per pound of steam per second. The difference as compared with the evaporator cooler is enormous. The Zoelly system of cooling involves the necessity of having a condenser and recooler, but affords important advantages. The coefficient of heat transmission from steam to water in a surface condenser is about 490 British thermal units per degree Fahrenheit per square foot per hour, whereas that for air-cooled condensers from steam to air is only a trifle over 8 British thermal units (1). The surface of the air condenser must therefore be 60 times that of a water-cooled condenser. This makes it possible to have on the Zoelly locomotive both condenser and turbines on the same truck as the boiler, thus overcoming all difficulties involved in having vacuum connections between tender and locomotive. The relatively small vacuum space is easily kept airtight while the system further allows of the locomotive's being the real driving part, thus adhering to this extent to the old and conventional design.

(1) R. P. Wagner, *Organ für die Fortschritte des Eisenbahnwesens*, 15 January 1924, p. 3.

It was of course impossible to calculate the recooler, and very extensive tests were necessary to clear up the very complicated relationship and to get the data for actual design. The complicated nature of the task of finding the most economical design, *i. e.*, getting the maximum of cooling effect for a given surface with the minimum of weight and driving power, will be seen from the numerous variable factors, viz., material of filling bodies, height, quantity of water, velocity of air, distribution of water, water and air temperatures, etc. As a result of all tests it was found that for average conditions — air 59° Fahr., cooling water 122° Fahr., corresponding to about 85 % vacuum — a cooling effect of 44 260 British thermal units per square foot an hour is obtained.

There still remain many interesting details in connection with this cooler, but their discussion would lead too far for the present paper, the scope of which is confined to giving a general idea only of the Zoelly turbo-locomotive.

Main turbine. — For turbine-driven locomotives superheated steam is used in any case, as this gives the highest efficiency. So long as it is necessary to use the conventional type of boiler it will scarcely be possible to assume other steam conditions than those obtaining for ordinary locomotives, say, 215 lb. pressure and 662° Fahr. temperature. The vacuum has been fixed in the preceding paragraphs and the output desired is given, so that as variable factors in the turbine calculation there are the turbine speed, the wheel diameters, and the number of stages. These elements have to be so chosen that the efficiency will be as high as possible. On the locomotive we are limited in the matter of wheel diameters as well as in the number of stages. If these are determined the speed is dictated any departure from which speed would mean a certain loss in efficiency, which within relatively wide limits is not of the utmost import-

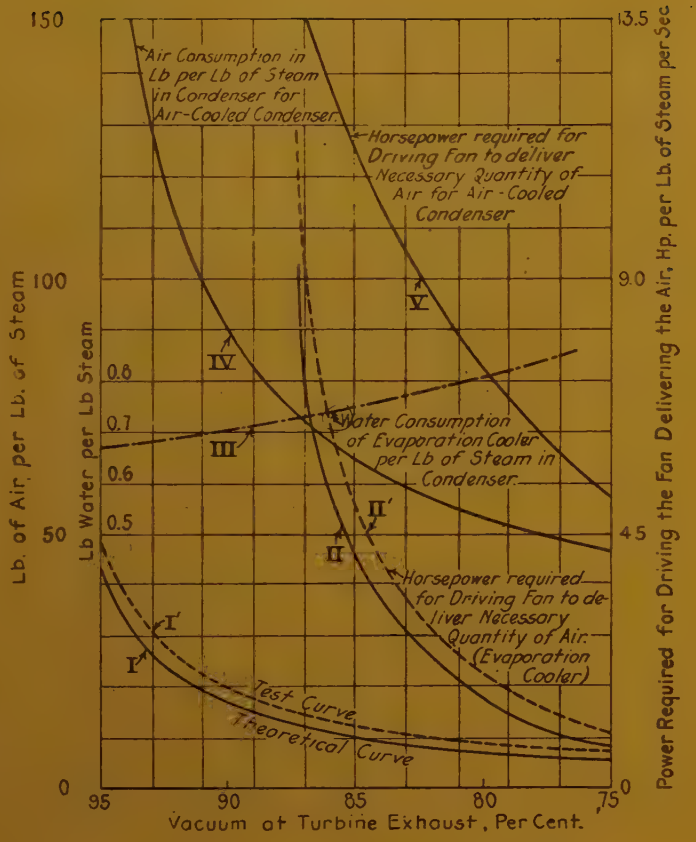

Fig. 5. — **Air consumption for evaporation and surface coolers.**

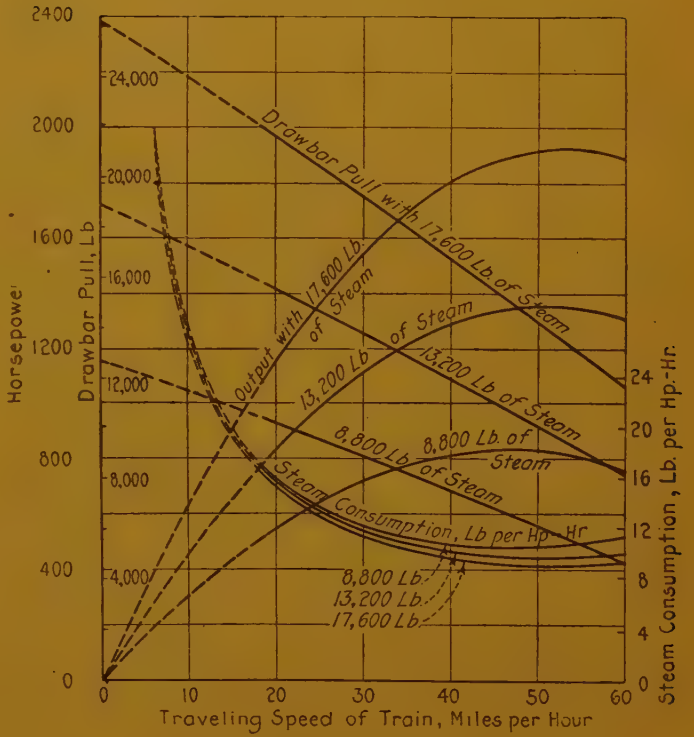

Fig. 6. — Output, drawbar pull, and steam consumption of 2 000 H. P. Zoelly turbo-locomotive for different speeds and steam quantities.

ance. The turbine speed determines the gear ratio and dimensions. For normal conditions the turbine speed ranges from 6 000 to 8 000 revolutions per minute, but it also depends upon the maximum speed the train can attain, this in turn being limited by the stresses allowed.

A locomotive turbine has to be calculated not only for one particular speed and one load, as is usually done for stationary plants, but for different quantities of steam flow and for different speeds for each steam flow, in order to obtain full information as to the performance of the locomotive. Such curves as calculated for a 2 000 H. P. Zoelly locomotive built by Krupp, showing output and drawbar pull for different speeds and steam quantities, are given in figure 6. For running astern a sacrifice in efficiency is admitted on account of the extreme limitation of space. The only point to consider is that sufficient initial torque must be available for accelerating the heaviest of trains.

Auxiliary turbines. — The limitation in size and weight is very important, but efficiency is also exceedingly important. Small wheel diameters call for multiple stages and the turbine would thus be too long. In order to overcome this difficulty several turbines are connected in series. This arrangement in conjunction with high running speeds (9 000 to 10 000 revolutions per minute) satisfies the demand for high efficiency combined with small dimensions.

Feedwater heating. — The heat contained in the smoke gases has long since been utilized in stationary plants, the economizer being a very wellknown device. Several feedwater heaters of this type have been tried for locomotives, but without success. The draft available in ordinary locomotives is not sufficient to overcome the additional resistance of such a heater. In turbine-driven locomotives, however, where the draft has to be produced artificially, this difficulty does not present itself and therefore waste-gas feedwater heaters can be employed to advantage. The gases leave the stack with a temperature of about 750° Fahr., and can be cooled down to about 350° Fahr., thus giving 95 British thermal units per lb., corresponding to about 1 lb. of feedwater. If the condensate leaves the condenser at a temperature of 122° Fahr. it will therefore be possible to heat the feedwater to 217° Fahr. The total heat of the steam in the boiler being 1 350 British thermal units the saving effected by heating the feedwater thus amounts to 7.5 %. It is a matter of practice to see how much of this heat can actually be utilized.

There are other possibilities of heating the feedwater with steam, which latter can be exhaust steam from auxiliary turbines or steam bled from the main or an auxiliary turbine. Steam being exhausted at atmospheric pressure from a back-pressure turbine, as in the case of the turbine driving the furnace fan of the experimental turbine, has a total heat of about 1 150 British thermal units. Were this steam used in a low-pressure turbine working to the condenser, probably 72 British thermal units could be transferred to useful work, but the steam would enter into the condenser with 1 080 British thermal units, of which 990 British thermal units, would go to the cooling water and thus be lost. Using the exhaust steam in the heater, all the 1 150 British thermal units, can be utilized. Under normal steam conditions the feedwater can be heated up to about 302° Fahr. The condensate having a temperature of 122° Fahr., we can therefore use 180 British thermal units per lb. of feedwater. The maximum quantity of exhaust steam which can be utilized is accordingly one-fifth of the quantity of condensate. To heat up to this high pressure of course, steam at a pressure higher than that of the atmosphere has to be used.

The greatest locomotive economy would be effected by preheating the combustion air with smoke gases and the

feedwater with steam in a series of feedwater heaters, all heated by steam of different pressures bled from the main turbine or by exhaust steam at suitable pressure. Steam bled from the main turbine or steam from the furnace-fan turbine will always be the most convenient, as the proportion of steam to feedwater is adjusted automatically.

Economies shown by tests.

Tests have been conducted with this experimental locomotive, but only over a line of 35 miles which had variable grades. This made it impossible to make coal-consumption tests. All that could be determined was the steam consumption which may be compared with that of a corresponding reciprocating locomotive making the same journey with the same load. Preheating was employed on the turbo-locomotive and only saturated steam was used for the auxiliaries. The consumption of heat in the turbo-locomotive for the round trip was only 4 230 000 British thermal units. An ordinary locomotive with the same train and identical operating conditions, will consume 5 904 000 British thermal units, calculated from the difference in water levels in the tender before and after the run and the initial steam conditions. These tests were repeated four times and the averages are given in Table I. The water consumption of the recooler was approximately 1 400 gallons. Quite a large amount of this water represented mechanical losses through leakage.

Operation and maintenance is comparatively simple.

In spite of the numerous parts comprising a turbo-locomotive, its operation is simple and less attention is required on the part of the personnel than is the case with the ordinary reciprocating locomotive. Before starting the locomotive the engineer speeds up the turbine driving the fan on the recooler.

This turbine is connected in series with the turbine driving the condensing auxiliaries and the condensing plant is started automatically. After the proper working vacuum has been attained, which requires several minutes, the steam-admission valve to the main turbine is opened wide and then it is only necessary to open or close the governor valve in order to start or stop the train. The exhaust fan should also be started as soon as the engineman starts to work the locomotive. The opening of this valve is governed in such a way that the boiler pressure is kept constant. Boiler feeding requires no attention from the engine crew, except to see that the pump is working properly. All that is required to keep the locomotive going at a certain speed is simply to throttle the steam admission to the required extent. If for any reason the output is insufficient when the governor valve is wide open, then the overload valve will allow an increase. The auxiliaries should not be shut down unless for a prolonged stop.

In order to run the locomotive backwards the valve for running ahead is closed and that for running astern is opened. The engineman then operates the governing valve as before.

The locomotive makes a smooth start which seems to contradict the opinion expressed by many engineers that a turbine-driven locomotive would not have sufficient initial torque to start a train. The running of the turbine-driven locomotive is smooth when compared with that of a reciprocating locomotive. Dynamometer tests taken on the Swiss Federal Railways showed that the pull at the drawbar was free from fluctuations.

A further development of the turbine-driven locomotive is at present impending which involves the employment of very high pressures. The practical utilization, however, depends upon the finding of a suitable boiler. As far as the turbine itself is concerned, the designs are ready.

TABLE I. — **Comparative steam and coal consumptions of different locomotive types.**

	Piston locomotives, non-condensing				Piston locomotives, condensing. Superheated steam.			Turbo-locomotive. With feedwater heating.		
	Superheated steam simple 2-cylinder.		Superheated steam 4-cylinder compound.							
	Without preheating.	With preheating.	Without preheating.	With preheating.	Simple without preheating.	Compound with preheating.	Without preheating.	With steam.	With smoke gases.	Preheating feedwater and combustion air.
Boiler pressure, lb. per square inch abs.	213	213	213	213	213	213	213	213	213	213
Pressure at steam chest, lb. per square inch abs.	199	199	199	199	199	199	199	199	199	199
Temperature in steam chest, degrees Fahr.	572	572	572	572	572	572	662	662	662	662
Exhaust pressure, lb. per square inch abs.	14.2	14.2	14.2	14.2	2.13	2.13	2.13	2.13	2.13	2.13
Steam per indicated horse power-hour (including all auxiliaries), lb.	16.97-16.28	16.97-16.28	16.5-15.61	16.5-15.61	13.83	11.55	10.59	11.08	11.08	11.08
Saving in steam consumption compared to simple locomotive working with superheated steam, non-condensing, lb.	0	0	0.47-0.67	0.47-0.67	3.14-2.45	5.42-4.73	6.38-5.69	5.89-5.20	5.89-5.20	5.89-5.20
Ditto, per cent	0	0	2.76-4.1	2.76-4.1	18.5-15.1	31.9-2.90	37.6-35.0	34.7-31.9	34.7-31.9	34.7-31.9
Total heat required in boiler per horse power-hour, British thermal units	44 860-41 680	33 830-32 470	36 850-34 880	32 910-31 140	30 410	25 510	20 120	19 510	17 980	16 410
Coal consumption (heating value of 11 700 British thermal units assumed), lb. per horse power-hour	3.23-3.10	2.88-2.77	3.14-2.97	2.81-2.52	2.60	2.18	1.72	1.67	1.54	1.40
Saving in coal compared to a simple locomotive working with superheated steam and feedwater heating, lb.	—0.35 to —0.33	0	—0.26 to —0.20	0.07-0.25	0.28-0.17	0.70-0.59	1.16-1.05	1.21-1.10	1.34-1.23	1.48-1.37
Ditto, per cent	—12.4 to —12.1	0	—9.3 to —8.9	2.43-8.9	9.5-5.65	24.1-21.0	40.0-38.0	41.8-39.5	46.5-44.4	51.1-49.2

TABLE II. — **Table of dimensions, weights and proportions.**

Railroad	Swiss Federal Railways.
Builders	Escher Wyss & Co., Zurich (Switzerland). Swiss Locomotive Works, Wintherthur (Switzerland).
Service	Experimental.
Turbine	6-stage impulse Zoelly.
Maximum speed, running ahead	7 500 revolutions per minute.
First gear reduction	1 to 7
Second gear reduction	1 to 4.1
Maximum speed	47 miles per hour.
Weights in working order :	
Total engine	130 000 lb.
On drivers	91 200 lb.
Wheel bases :	
Driving	12.3 feet.
Total engine	25 feet.
Total engine and tender	58.4 feet.
Wheels, diameter outside tires :	
Driving	60 inches.
Front truck	33 inches.
Boiler :	
Type	Conical.
Steam pressure	200 lb. per square inch.
Superheat	662° Fahr.
Fuel, kind	Bituminous.
Grate area	25 square feet.
Heating surfaces :	
Firebox and combustion chamber	132.5 square feet.
Tubes and flues	927.5 square feet.
Total evaporative	1 060 square feet.
Superheating	380 square feet.
Combined evaporative and superheating	1 450 square feet.
General data estimated :	
Turbine horsepower	1 000 H. P.

The advantages of the turbo-locomotive are many. Some of them are, high economy in fuel, amounting to nearly 50 %; low water consumption and the water not necessarily being good boiler water; the boiler can be kept clean, and smooth running conditions obtained on account of the absence of reciprocating parts. It is predicted that the turbine-driven locomotive will soon enter into successful competition not only with the reciprocating locomotive but also with plans for electrification which are expected to result in greater efficiency in the utilization of coal. Its greater economy gives increased capacity with the same boiler and thus opens a new era of steam-locomotive traction.

MISCELLANEOUS INFORMATION

[625 .143.1 (.73)]

1. — Develop new rail section.

Fig. 1, p. 67.

(*Railway Age.*)

The use of the « head-free » type of rail joint manufactured by the Rail Joint Company, New York, has led to the development of a new rail section that embodies a marked departure from current practice. In the head-free joint the upper bearing of the joint bar against the rail is confined to a curved surface fitting the fillet under the rail head. Thus the upper fishing surface of the rail is not brought into play but all adjustment of the joint bar against the rail is obtained by movement on the lower fishing surface.

Since the upper fishing surface serves no useful purpose with this type of joint it was suggested that the material required in the two lower corners of the rail head to form the fishing surfaces could very well be placed elsewhere in the section where it would be of

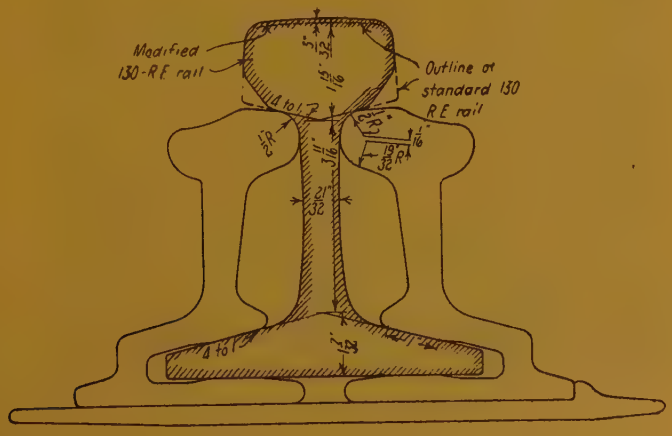

Fig. 1. — The new rail section in its relation to the « head-free » joint and the standard R. E. section.

more value. This thought led to the development of the section shown in the drawing in which the lower corners of the head have been camfered and the metal thus saved added to the top of the head.

In the section designed for 130-lb. rail, which is the one shown in the diagram, the increase in the thickness of the head is 3/32 inch, and as the remainder of the section is exactly the same as the standard 130-lb. R. E. section the total height of the rail has been increased by this amount. The Reading Company has

recently ordered 10 000 tons of rail to be rolled according to this section for a trial installation. The advantages which it is expected to gain from this rail include a better texture in the steel due to more advantageous rolling, greater girder strength, greater permissible limits of wear and therefore longer life. The new section has been developed by the Thompson Rail Corporation, New York.

[385. (09.1 (.496 + .56)]

2. — The railways of the Ottoman Empire.

(*Rivista tecnica delle ferrovie italiane*).

The actual railways which were operating in the Ottoman Empire before the war were as follows :

1) *State Railways :* The Hedjaz Railway, about 250 km. (155 miles) in length;

2) *Private companies :*

In Turkey in Europe : The Oriental Railway, 975 km. (605 miles) ; Salonika-Monastir Railway, 224 km. (139 miles) ; the Salonika-Constantinople Railway, 510 km. (317 miles) ;

In Turkey in Asia : The Smyrna-Cassaba and Extension Railway, 702 km. (436 miles) ; the Smyrna-Aïdin and Extensions Railway, 590 km. (366 miles) ; the Moudania-Broussa Railway, 41 km. (25 miles) ; the Anatolian Railway, 1 024 km. (636 miles) ; the Bagdad Railway, 900 km. (560 miles) ; the Damas-Hamah and Extensions Railway, 580 km. (360 miles) ; the Jaffa-Jerusalem Railway, 84 km. (52 miles).

The working of these lines has been carried on, first under the control of the Turkish State, then under the English, French and Belgians, and finally by the League of Nations.

[625 .142.4 (.73)]

3. — Experiments with concrete ties.

Figs. 2 and 3, p. 69.

(*Engineering News-Record.*)

Satisfactory experience with a trial lot of twenty-two reinforced-concrete ties laid in May 1916, at Eagle Pass, Texas, has led the Southern Pacific Railway, to make a hundred ties of the same type, which are to be placed in heavy-traffic main-line service. According to a statement by H. M. Lull, chief engineer, in the 1925 report of the tie committee, American Railway Engineering Association, relative to an inspection made in 1924 : « The ties are apparently in as good condition as when they were installed. There is no indication whatever of impending failure. »

This present installation, with nine years' service, is shown in figure 3, the track being opened up for a change in grade made necessary by raising the level of the adjacent bridge, just beyond where the man stands on the track. With ties spaced 18 to 26 inches centre to centre the track has kept in good line and surface, and is said to have required practically no tamping to maintain its surface. While the regular traffic is light, amounting to only about six trains daily, it is stated that there are frequent movements of switching engines, with the stopping and starting of heavy loads on this piece of track. Another installation of thirty-seven ties of the same type has been made on the standard-gage main line to the mines of the New Sabinas Co., at Cloete, Coahuila, Mexico. It is expected that concrete ties will be used in all future renewals on this line.

All these ties are of the form shown in

figure 2. At the ends they are of rectangular section, 8 × 12 inches, with recesses for wood blocks 8 × 6 × 14 inches, to which the rails are spiked. The blocks absorb vibration and

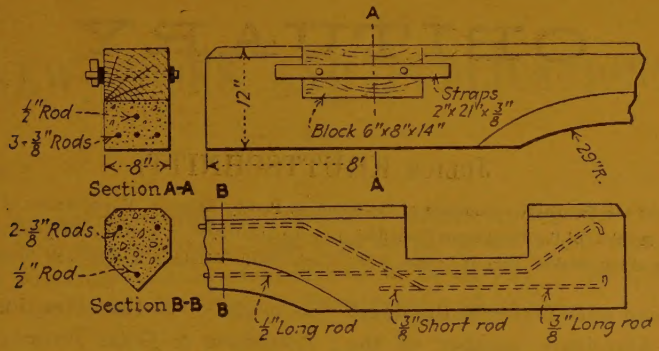

Fig. 2. — The « indestructible » concrete tie.

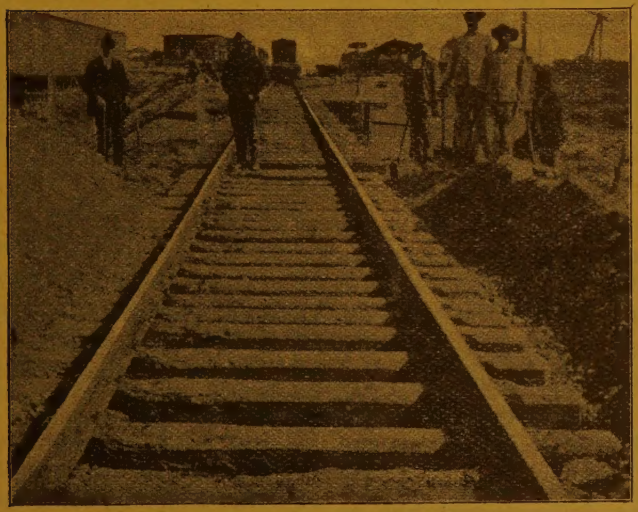

Fig. 3. — Concrete ties at Eagle Pass, Texas.

take the wear, so that there is no wear or disintegration of the concrete. They are held in place by iron straps and key-bolts, the bolts being slotted for vertical cotters or keys, as shown. At the middle, the tie is reduced to 10 inches in depth and is wedge-shaped on the bottom so that there is no tendency for the track to become center bound. A gravel concrete of 1:2:4 mix was used for the ties, with steel reinforcing rods arranged as shown in the drawing. These ties were invented and patented by F. C. Shearer, engineer for the U. S. Indestructible Tie Mfg. Co., Eagle Pass, Texas.

OBITUARY

Julius KRUTTSCHNITT,

Chairman of the Executive Committee of the Southern Pacific Railroad, United States of America;
Formerly a member of the Permanent Commission of the International Railway Congress Association;
Delegate of the sessions held at London (1895), Paris (1900), Washington (1905) and Berne (1910).

We have heard with regret of the death of a former American member of the Permanent Commission, Mr. Julius Kruttschnitt, who died in New York on the 15 June last.

Mr. Kruttschnitt had undergone a minor operation from which he was apparently recovering, when he succumbed to a heart attack.

He occupied a prominent position in the railway world of the United States, and was elected a member of the Permanent Commission of our Association in July 1901. He was a member of the Local Organising Committee of the seventh session (Washington 1905), and at that session carried out the duties of President of the 1st section (Way and Works) with distinction.

His numerous duties forced him to resign his seat on the Permanent Commission in 1910.

Mr. Kruttschnitt was born at New Orleans (Louisiana) on the 30 July 1854. He received his technical education at the Universities of Washington and Lee and graduated with the diploma of Civil Engineer.

He entered the railroad service in 1878 as engineer of the extension on Morgan's Louisiana & Texas Railroad and Steamship Company, and between the 1 January 1880 and the 1 April 1883, occupied successively the positions of roadmaster of the Western division, assistant chief engineer and general roadmaster and chief engineer and superintendent of that Company.

On the 1 October 1885 he joined the Southern Pacific Company as assistant manager of their Atlantic system, becoming general manager on the 1 July 1889, and in addition, vice-president of the Galveston, Harrisburg & San Antonio Railway and of the Texas & New Orleans Railway.

Ten years later he became general manager of all the lines of the Southern Pacific Company, being elected vice-president also in April 1898 and chairman of the Executive Committee of directors in January 1913.

Mr. Kruttschnitt was also president or director of several other railroads in the United States.

We offer to his family our sincere sympathy.

The Executive Committee.

NEW BOOKS AND PUBLICATIONS

[621 .33 (02]

BACHELLERY (A.), engineer in charge of Traction to the Midi Railway of France. — **Chemins de de fer électriques (Electric railways).** — One large volume in 8vo (9 × 6 inches) of 445 pages, with separate engravings and numerous illustrations in the text. — 1925, Baillière & Son, Publishers, 19, rue Hautefeuille, Paris. — Price (bound) : 55 francs.

Under the above title has just been published an excellent book dealing with the advance of electric traction, as applied to ordinary railways, in all its detail.

The author, in his preface, expresses himself in these terms : « It has been stated that this book, compared with those devoted to different branches of electric technology, will hold a unique position, being a work on electric railways from the point of view of a railway engineer. »

He has also kept well within the limits of his subject, and has not dealt with questions concerning electric tramways, but only with railways properly called, nor does he touch on the construction and testing of motors or control gear.

The first three chapters comprise general remarks on electric traction with different systems and on matters relating to the running of power stations, power lines and sub-stations.

Chapters IV to VIII deal with the different sections of electric traction, *i. e.*, conductors and pick-up gear, the motors, the acceleration of locomotives, the methods of transmitting the power to the axles, the general lay-out of electric locomotives. After giving many details about rack locomotives and electric adhesion locomotives, the book closes with a special note on the working of electric railways and the construction of electrified lines.

The book consists of 400 pages and 224 figures, and is written with extreme clarity; it forms a lengthy document and allows all engineers, through the numerous references cited and the most complete index, to refer to any subject of special interest. The book has the merit of stating completely and accurately the actual position of electric traction as applied to ordinary railways.

It is certain that this book will have the success it deserves.

E. U.